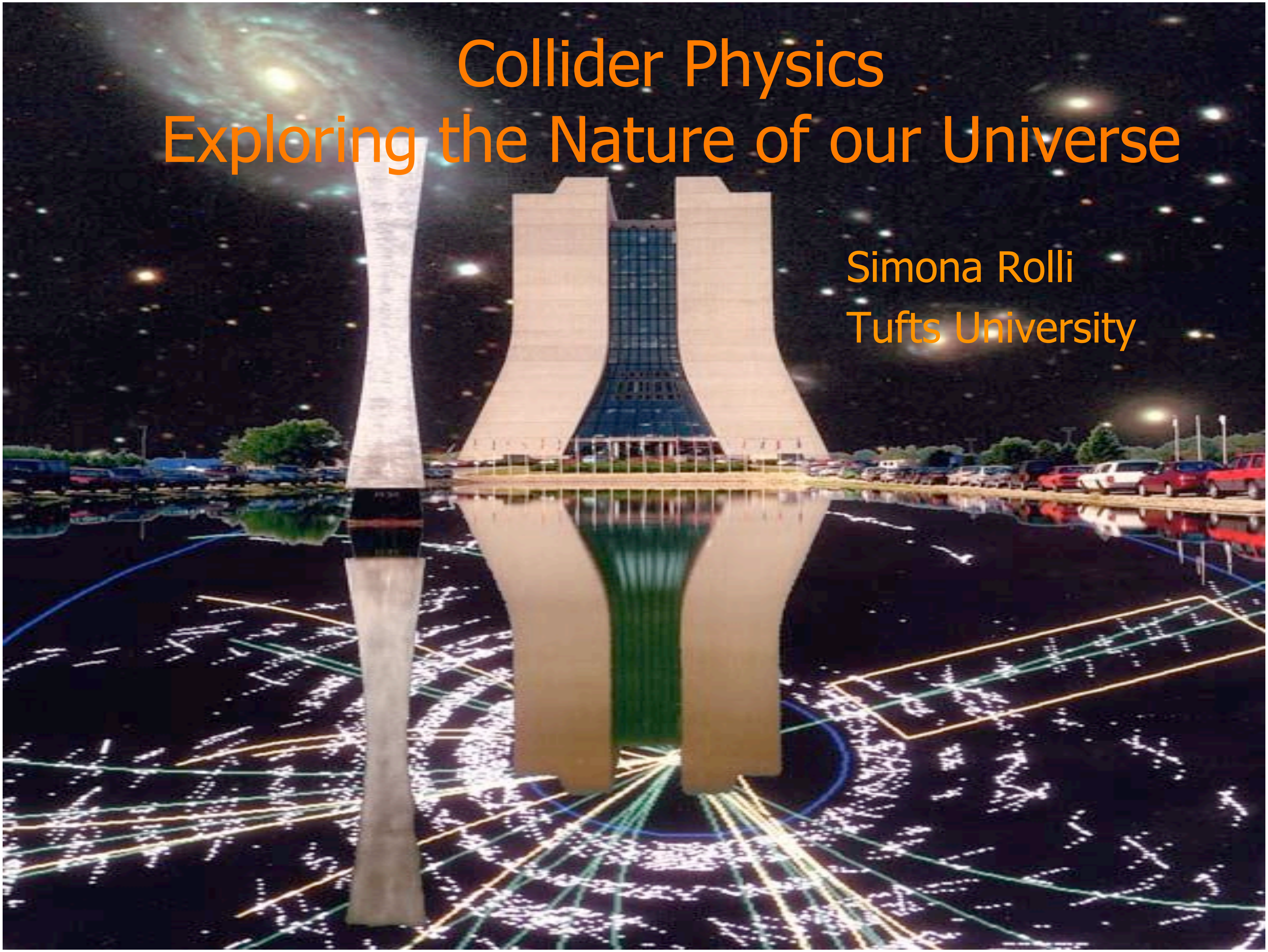
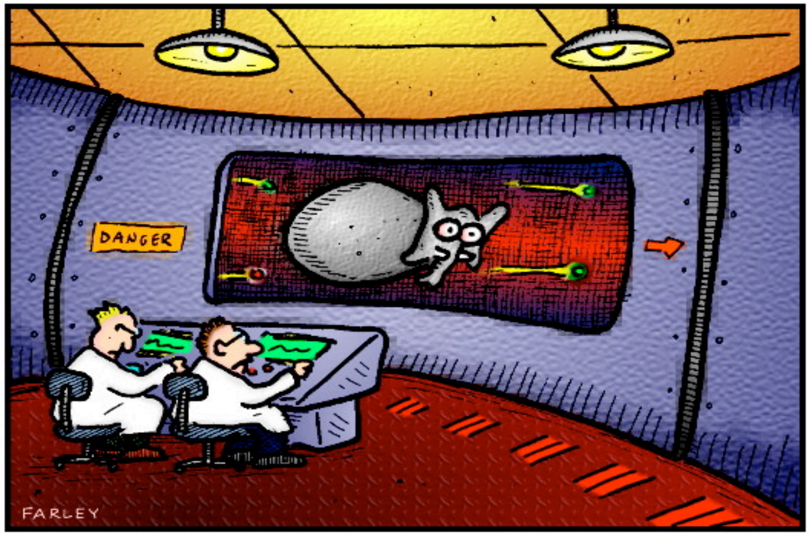

Collider Physics
Exploring the Nature of our Universe
Simona Rolli
Tufts University

Introduction



Deep within the atomic supercollider, the search continues for the elusive elephantino.

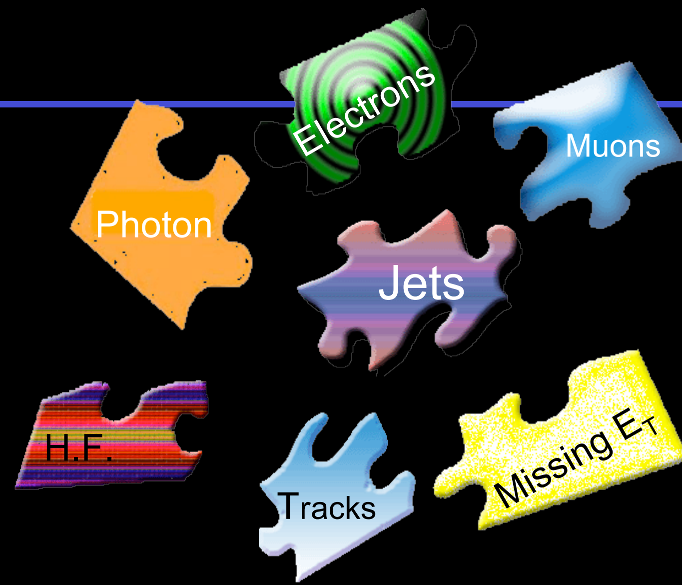
A (small) community of scientists is building more and more powerful machines to explore the intimate nature of matter and answer some of the fundamental questions about our Universe

Particle Physics has evolved from small laboratory experiments to world-wide enterprises lasting several years and involving several thousand people per experiment

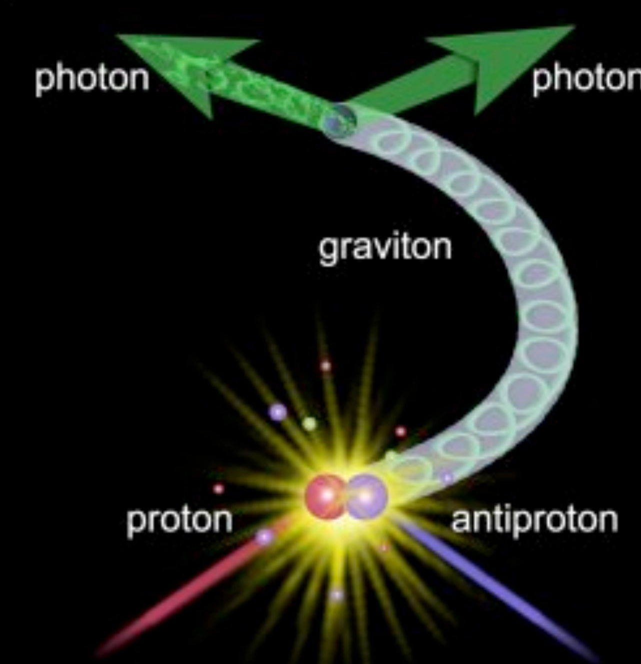
Not all the questions have received an answer yet.

The search is still on….

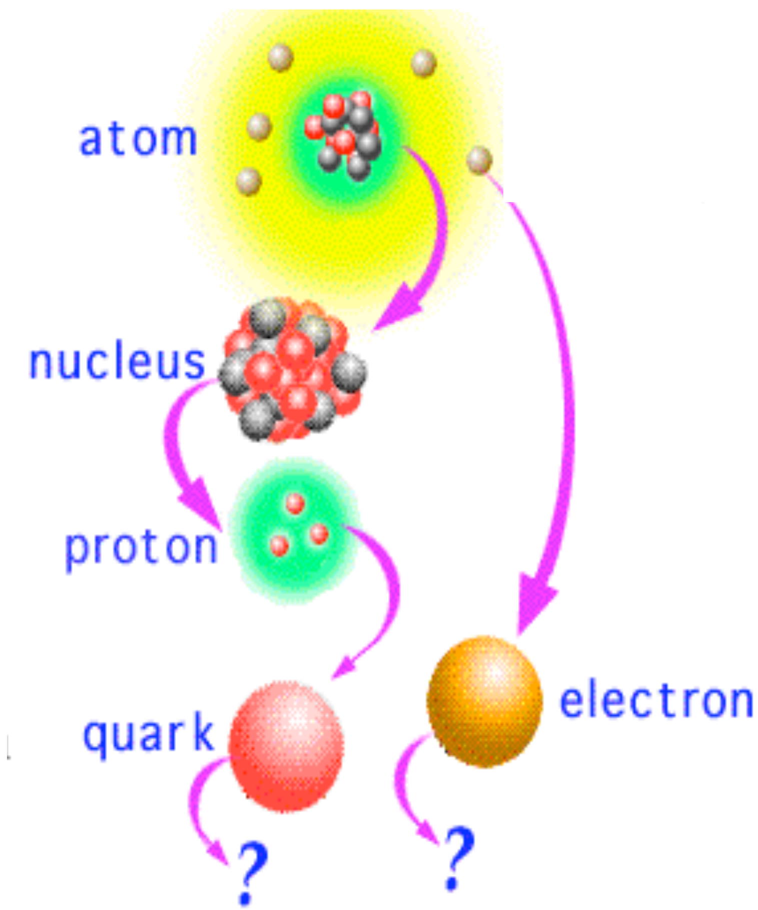
Outline of the talk



- **What is the Universe made of ?**
  - **The Standard Model of particle physics**
- **The Experimental Apparatus**
  - **The Collider**
  - **The detectors**
  - **From 540 GeV to 14 TeV in 30 years**
- **Physics Processes and their Signatures**
  - From Jets to W/Z to the Top quark and Beyond
  - From the SppS to the Tevatron
    - Current status
  - The future is here: LHC
    - What to expect



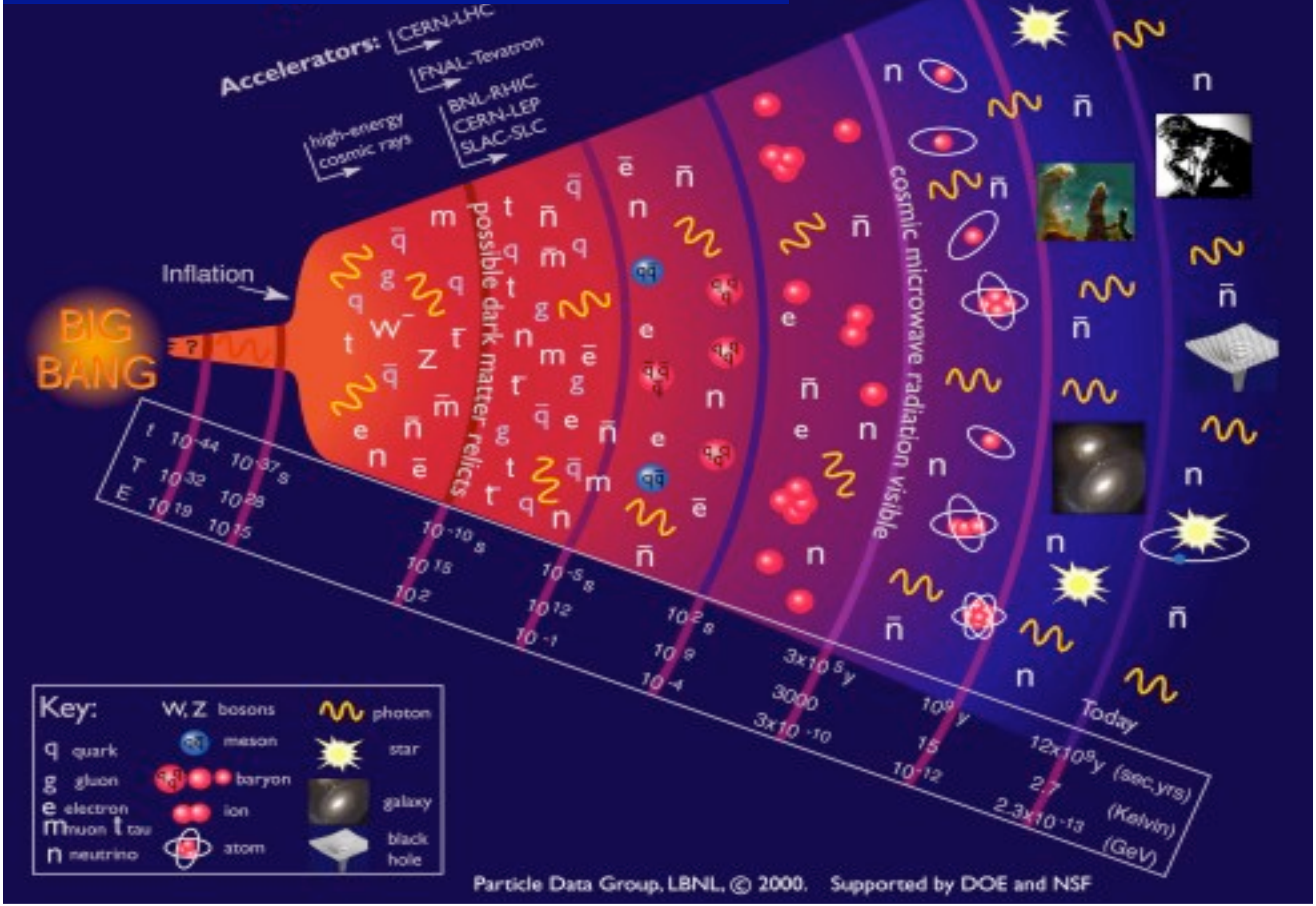
What is the Universe made of?



- Everything we see is made of molecules or chains of atoms
- Atoms contain a nucleus surrounded by electrons
- In the nucleus there are protons and neutrons
- Protons and neutrons are bound states of quarks and gluons

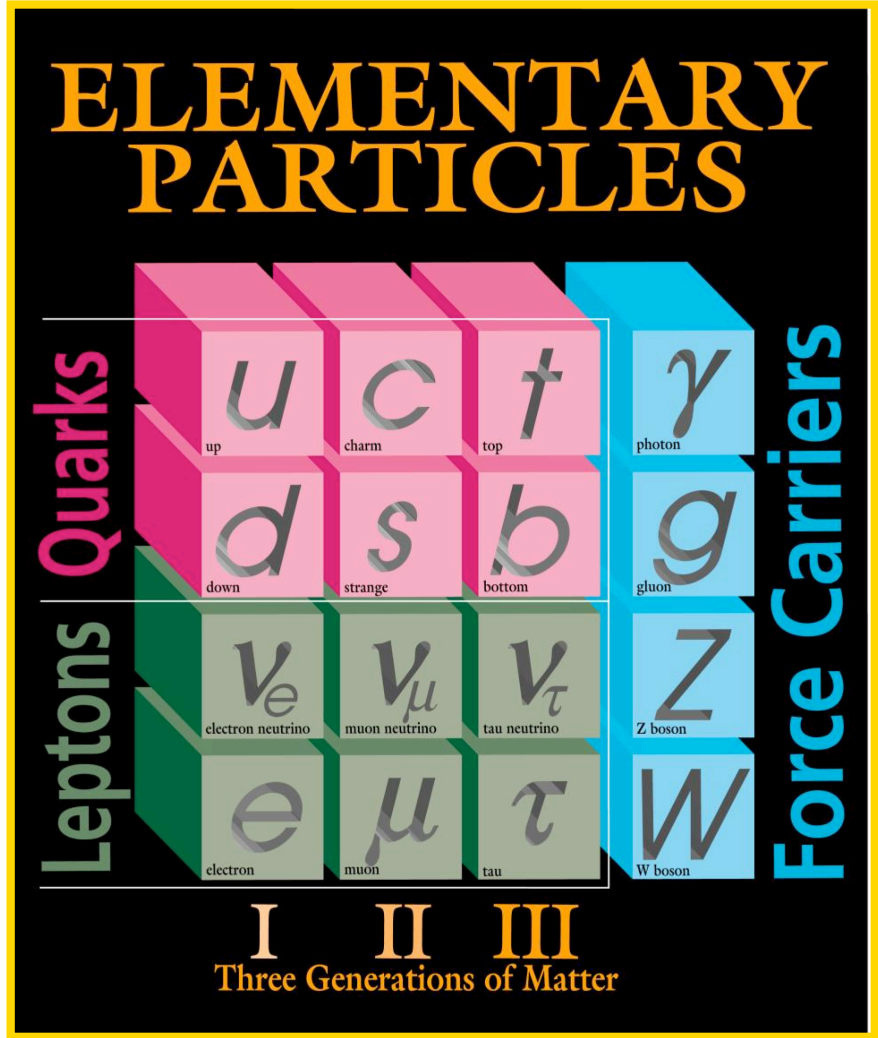
- When we look closer we find an amazing world of particles and interactions and we travel back in time…..

Particles and Time



The Standard Model of Particle Physics

- The Standard Model describes the fundamental particles and the interactions between them
- Leptons like electrons are believed to be fundamental
- Hadrons are composite states of quarks and gluons;
  - Baryons (three quarks like protons and neutrons)
  - Mesons (a quark and one anti-quark)
- Force carriers are particles responsible for the interactions
- Collider experiments can identify all types of particles



Timeline of Particle Discoveries

1895 The **electron** is discovered, except electrons are called **cathode rays** by their discoverer.

1896 **X rays** and other forms of radioactivity are observed

1899 **Alpha particles** are discovered, and later shown to be helium nuclei consisting of two neutrons and two protons.

1911 Nuclear model of **atom** with heavy nucleus in the middle and light electrons orbiting around it, is proposed, and becomes accepted.

1911 **Electron charge** measured in an oil drop experiment indicates that all electrons carry the same electric charge.

1932 The **neutron** directly observed in an experiment for first time.

1932 The **positron**, predicted by a theorist in 1928, is discovered.

1934 Radioactive **nuclei** produced in the laboratory.

1937 The **muon**, a charged lepton like the electron only heavier and hence unstable, is discovered.

1947 Two **charged pi mesons**, with positive and negative charge, are discovered.

1950 The **neutral pi meson** is discovered.

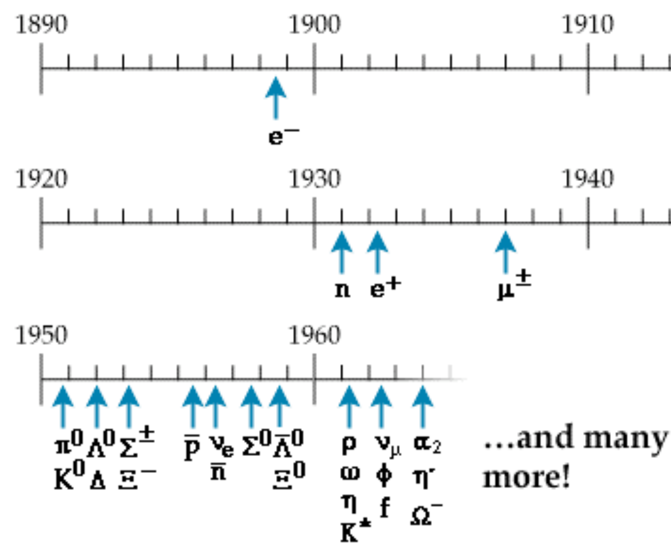
1953 The **lambda baryon** and **K meson** are discovered.

1956 The **electron neutrino**, predicted by theory in 1930, is confirmed to exist.

1950s-1960s Lots of **baryons** and **mesons** being discovered, and their properties occur in regular patterns that look as if baryons and mesons are made of smaller building blocks. Physicists exhibit a tendency to name new particles after letters in the Greek alphabet.

1961 The **muon neutrino** is discovered and shown to be a different particle from the electron neutrino..

1963 **Quark** theory postulates that protons are made of smaller particles that carry charges that come in thirds of the electron charge. The three flavors of quarks are given names: **up**, **down** and **strange**.



Timeline of Particle Discoveries

1970s Deep inelastic scattering and other experiments reveal more of the quark structure inside protons and other hadrons.

1974 A fourth flavor of quark, named **charm**, is detected in a newly discovered meson called the **J** (aka the yor **Psi**).

1975 The **tau lepton** is discovered, making a triplet of charged leptons with the electron and muon, leading to predictions of a **tau neutrino** to accompany the electron neutrino and the muon neutrino.

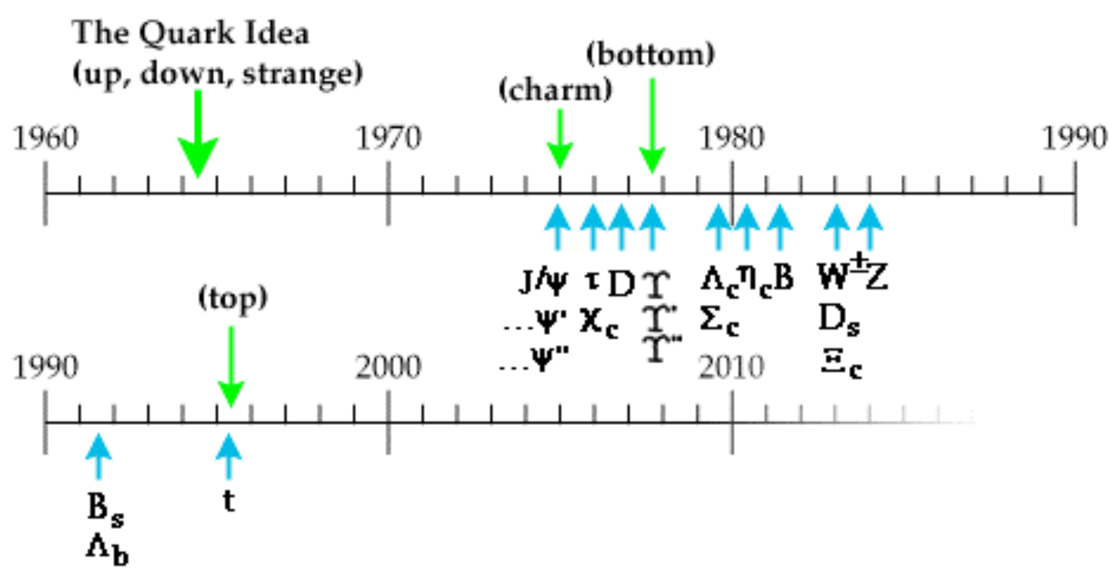
1979 A fifth flavor of quark, named **bottom**, is detected in the newly discovered Upsilon meson. This pattern leads particle physicists to believe they will find a sixth and final flavor of quark some day. This predicted last flavor of quark is called **top**.

1983 The massive gauge bosons that carry the weak nuclear force, called the $\mathbf{W^+}$,$\mathbf{W^-}$ and $\mathbf{Z^0}$, are discovered and the Standard Model of Particle Physics is confirmed.

1989 The lifetime of the $\mathbf{Z^0}$ weak nuclear gauge boson is measured, and agrees precisely with there being exactly three kinds of neutrinos, and no more.

1995 The **top quark** is finally directly observed and measured, confirming the predictions of theorists that there are six flavors of quarks, as described in the Standard Model.

Future The search goes on for the **Higgs boson** (the only particle predicted by the Standard Model that hasn't been seen yet), for **supersymmetric particles** predicted by string theory, for proton decay and for **magnetic monopoles** predicted by Grand Unified Theories, and **new kinds of exotic unpredicted particles** is ongoing. Perhaps in a few years there will be some more interesting entries for this page. Come back later and see.



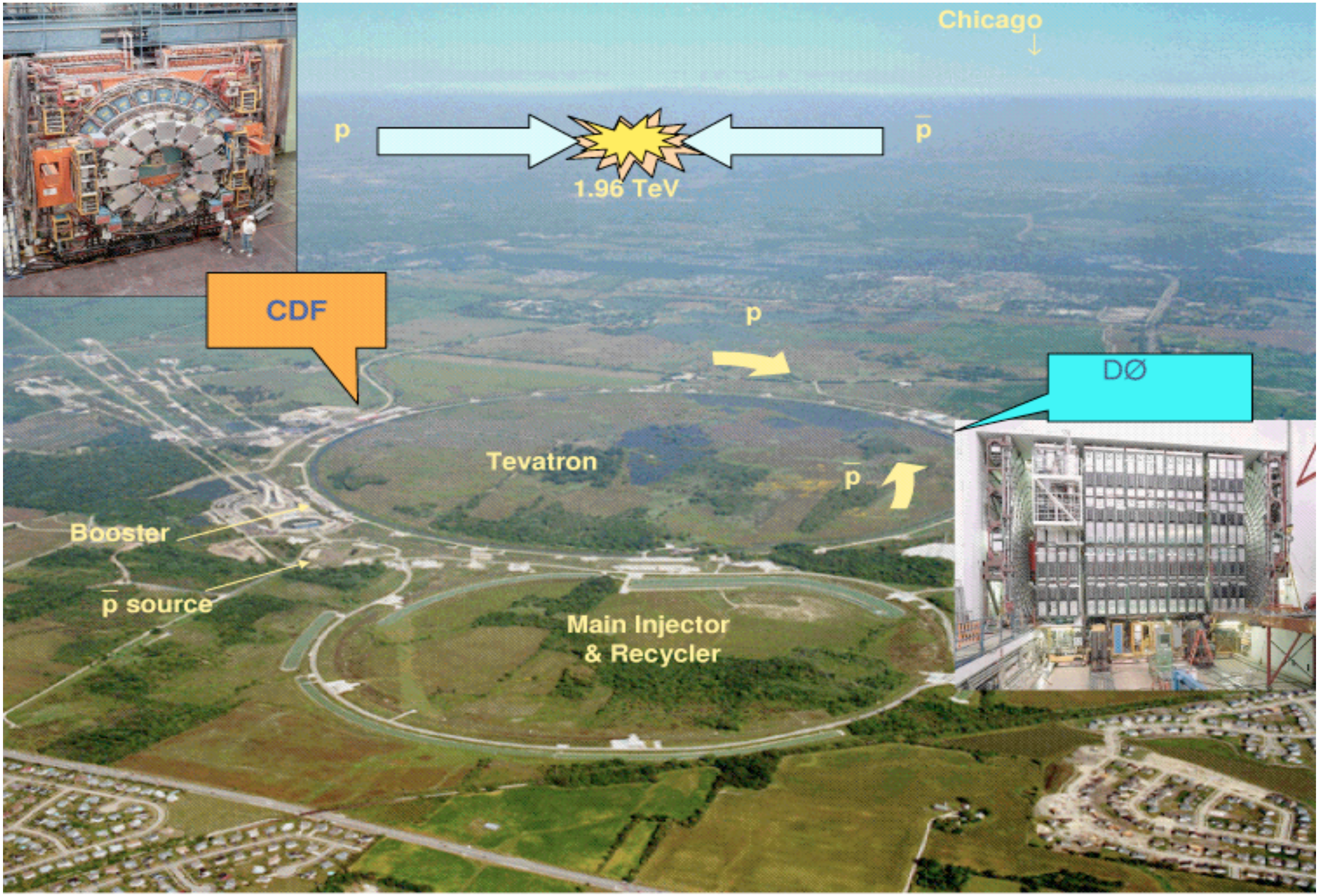
The Thrill of Discovery: A Brief History of CDF

- 1985: First collisions with partial detector
- 1987: Core detector in place. Jet Physics
- 1988-89: "Run 0" 4x the expected data, seen lots of W/Z's
- 1992-1995 : "Run I" -added silicon detector. Top quark discovered!

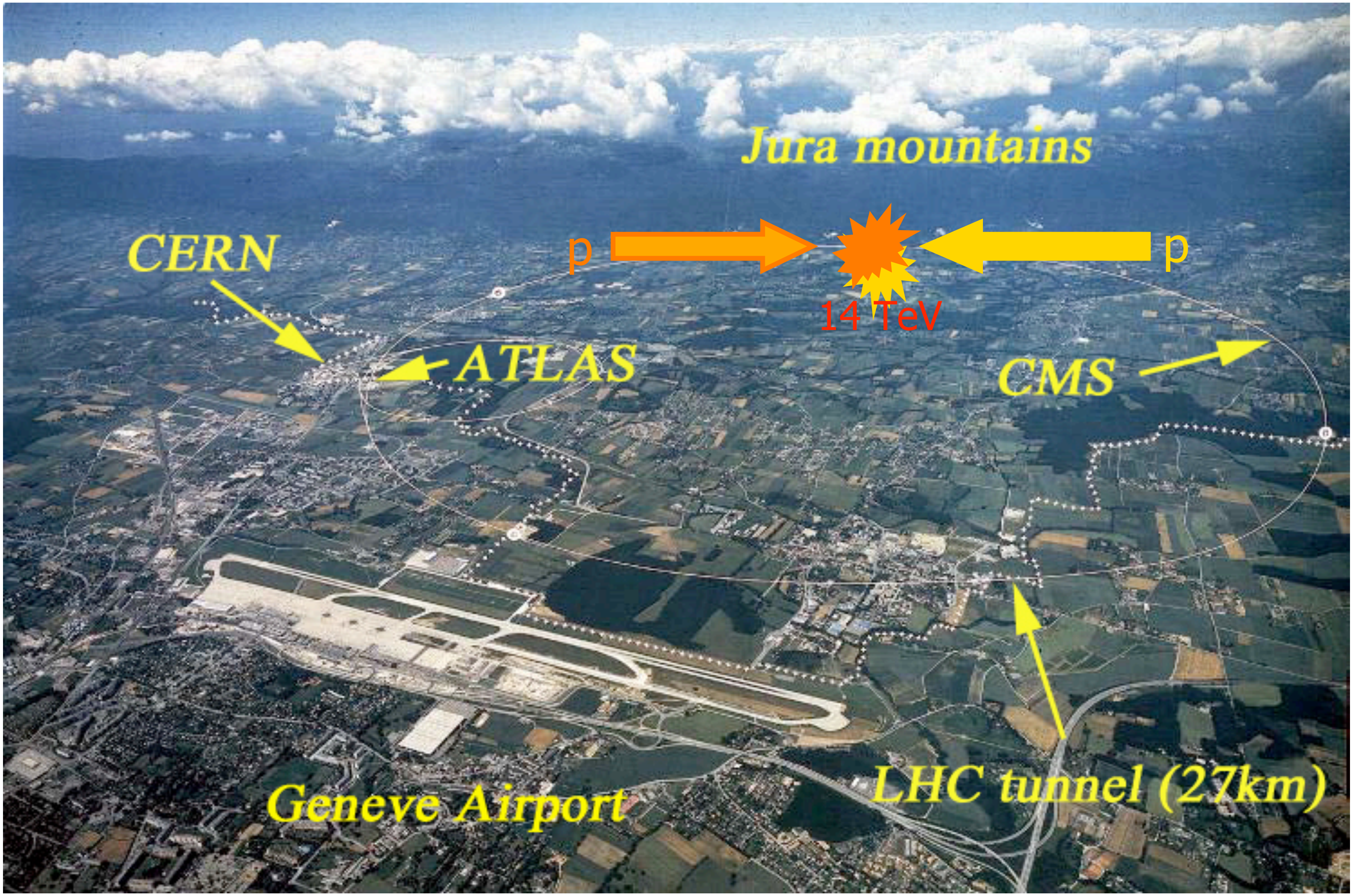
- 2001: Run II era begins with essentially a new detector, higher collisions energy and more data.
- 2004: First Run II physics papers published
- 2007: trying to catch the Higgs

12 countries, 59 institutions
706 physicists

The Experimental Apparatus: Fermilab



The Experimental Apparatus: CERN



The Accelerator Chain (Fermilab)

At Fermilab, we start by accelerating protons in the C-W (750 KeV) to the Linac and Booster (up to 8 GeV)

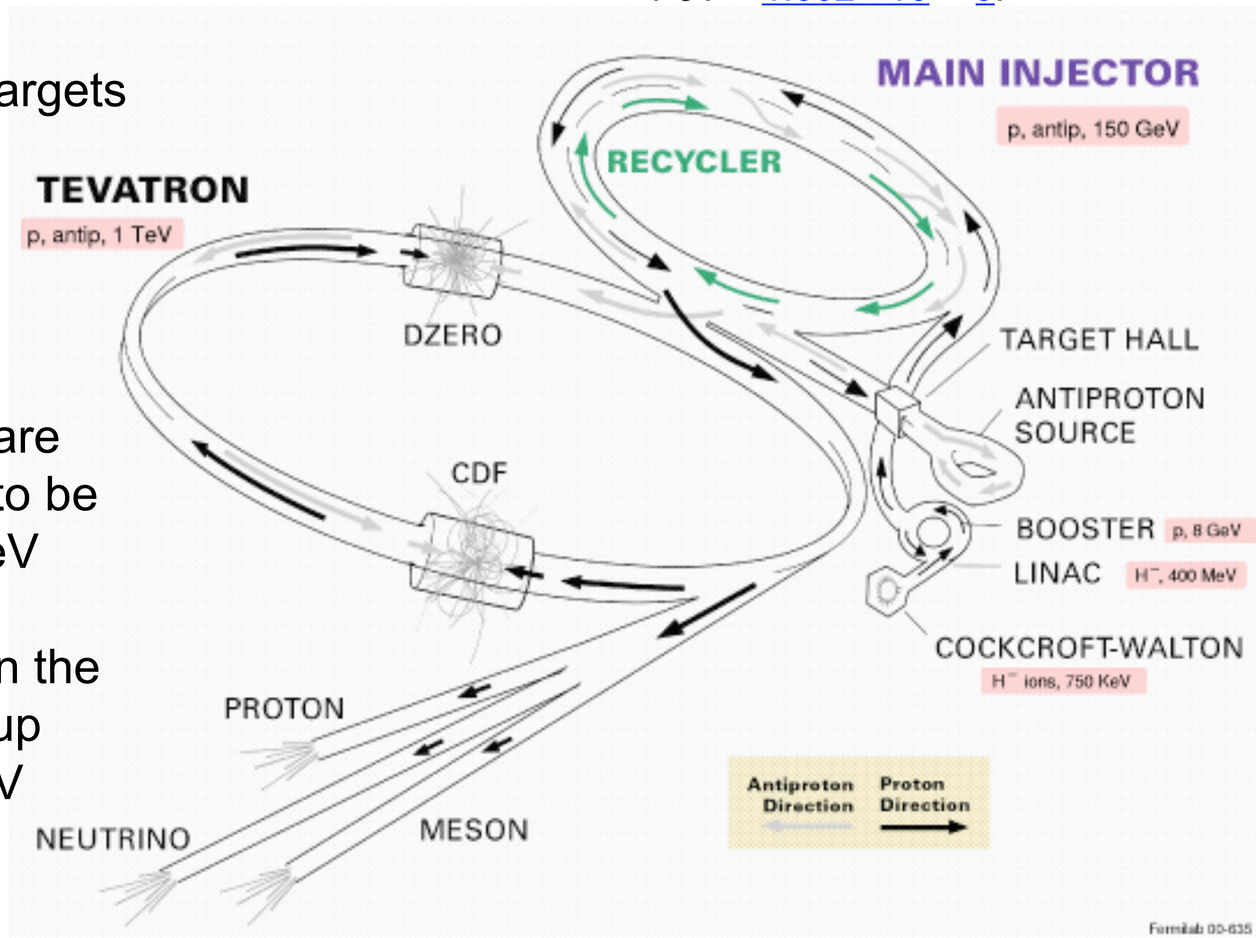
Some protons hit (gold) targets to make antiprotons

Antiprotons are stored (precious!)

Protons and antiprotons are sent to the main injector to be accelerated up to 150 GeV

They finally get injected in the TeVatron, which ramps up the beam energy to 1 TeV

An **electronvolt** (symbol: eV) is the amount of energy gained by a single unbound electron when it falls through an electrostatic potential difference of one volt. Very small amount of energy: 1 eV ≈ 1.602×10^{-19} J.



A small digression on Luminosity

The event rate $\mathcal{R}$ in a collider is proportional to the interaction cross section σ_{int}
The factor of proportionality is called instantaneous Luminosity $\mathcal{L}$

$$\boxed{\mathcal{R} = \sigma \times \mathcal{L}}$$

The instantaneous luminosity depends on the number of bunches n_1 and n_2 of particles colliding, their frequency f and the gaussian beam profiles $\sigma_x \sigma_y$

$$\boxed{\mathcal{L} = f\, n_1 n_2 / 4\pi\sigma_x\sigma_y}$$

Typical values for past, present and future colliders:

- SppS: $10^{27\text{-}28}$ cm^{-2}s^{-1}
- TeVatron: 10^{32} cm^{-2}s^{-1}
- LHC: $10^{33\text{-}34}$ cm^{-2}s^{-1}

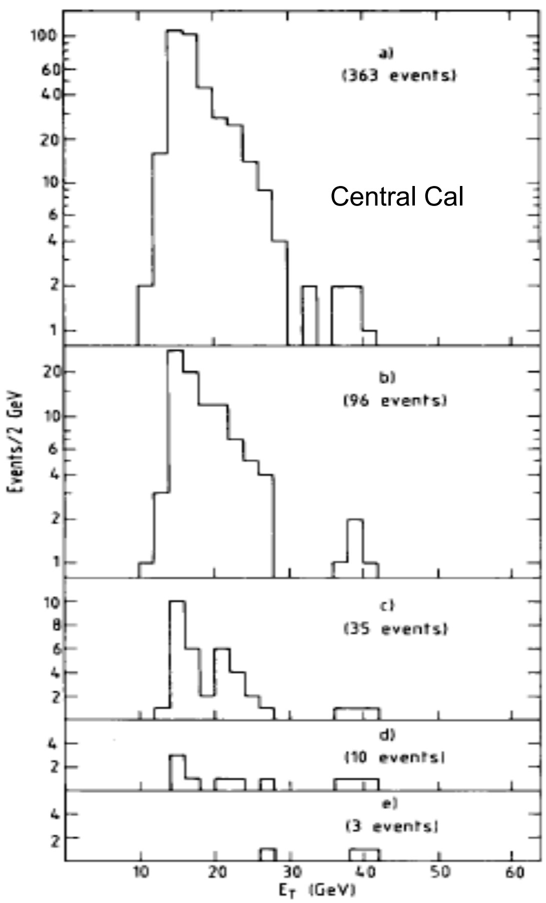
1picobarn(pb) = 10^{-36} cm^2

The real important quantity is the integrated Luminosity, expressed in units inverse to the cross section, pb^{-1}, fb^{-1}.
It tells us the number of events we can see during the lifetime of the experiment!

The discovery of the IVB (CERN 1983)

Proton-antiproton collisions at $\sqrt{s} = 540 GeV$ $\sim 20\ \mathrm{nb}^{-1}$

Search for W bosons at UA2
4 events!



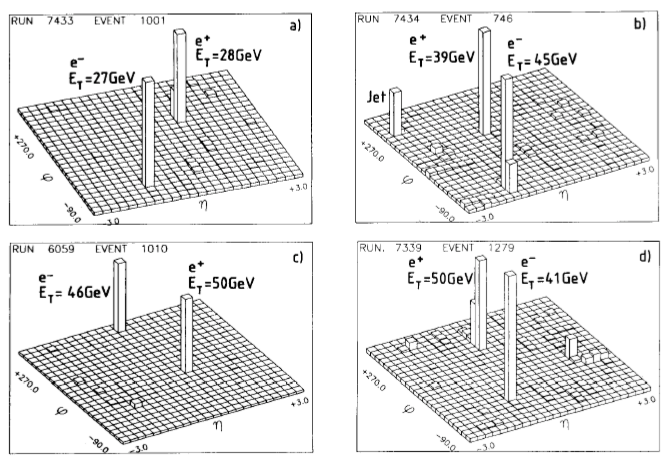
$m_{W^\pm} = 82.1 \pm 1.7$ GeV

$m_{Z^0} = 93.0 \pm 1.7$ GeV

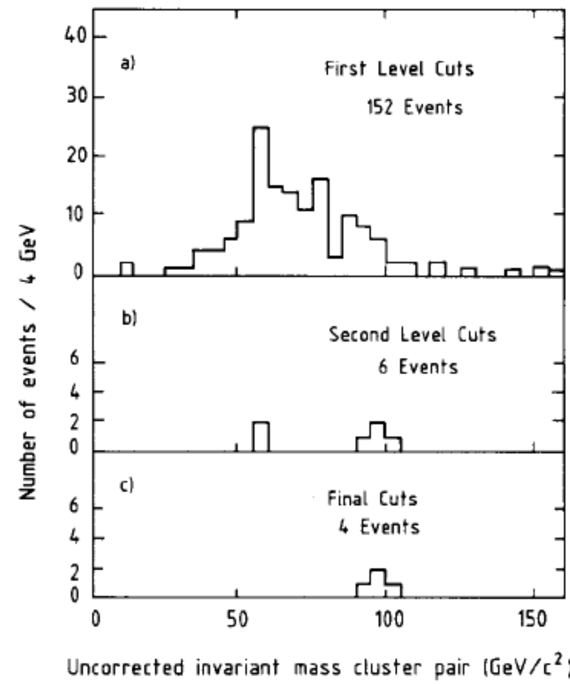
Current values (Particle Data Group 2006):

$m_{W^\pm} = 80.403 \pm 0.029$ GeV

$m_{Z^0} = 91.1876 \pm 0.0021$ GeV

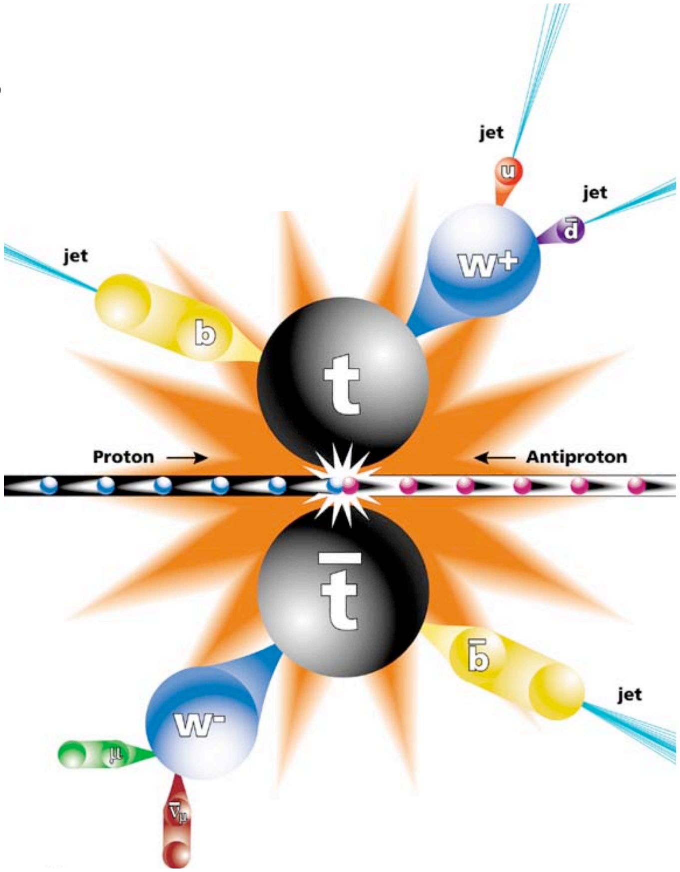


Search for Z bosons at UA1
4 events!



Proton-(Anti)proton Collisions

- Collisions:
  - At high energies we go inside the protons and antiprotons where we collide the internal quarks and gluons
- E = mc^2
  - Energy and mass are equivalent. With lots of energy we can produce lots of particles
  - 0.54 -0.63 TeV (SppS)
    - 1.8 -1.96 TeV (TeVatron)
      - 14 TeV (LHC)

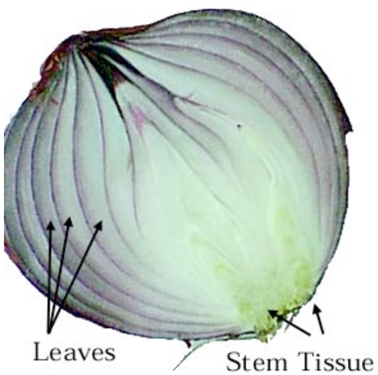


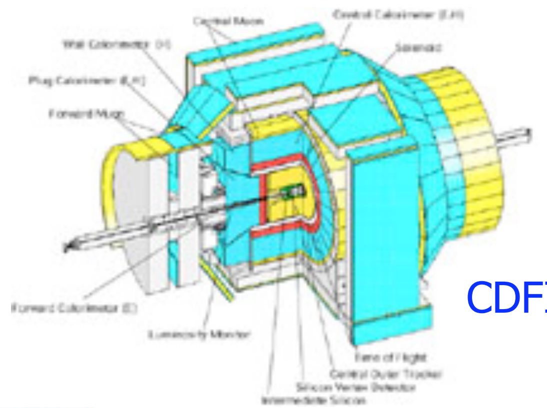
- Production
  - In the collision process we can produce several types of particles and study their properties
- Decay
  - Some particles decay and the study of their daughters gives us insight on the nature of the interactions

The Detector

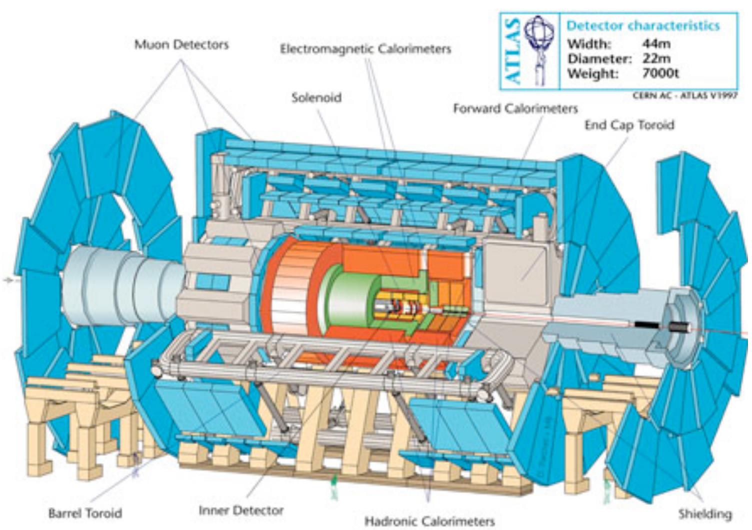
The Experiment studies *interesting* collisions between protons and antiprotons
- events of interest are selected (trigger)
- the interaction of particle and matter is used to identify the physics objects

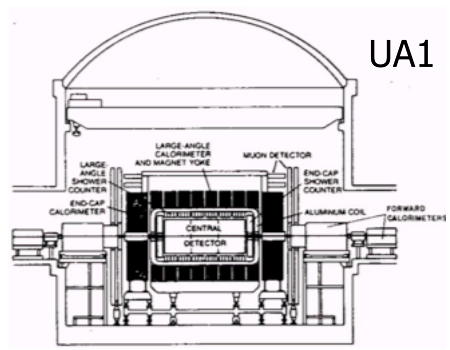
a multipurpose detector is like a large onion….





CDFII





UA1

Charged particles leave tracks in a magnetic field (inner layer)

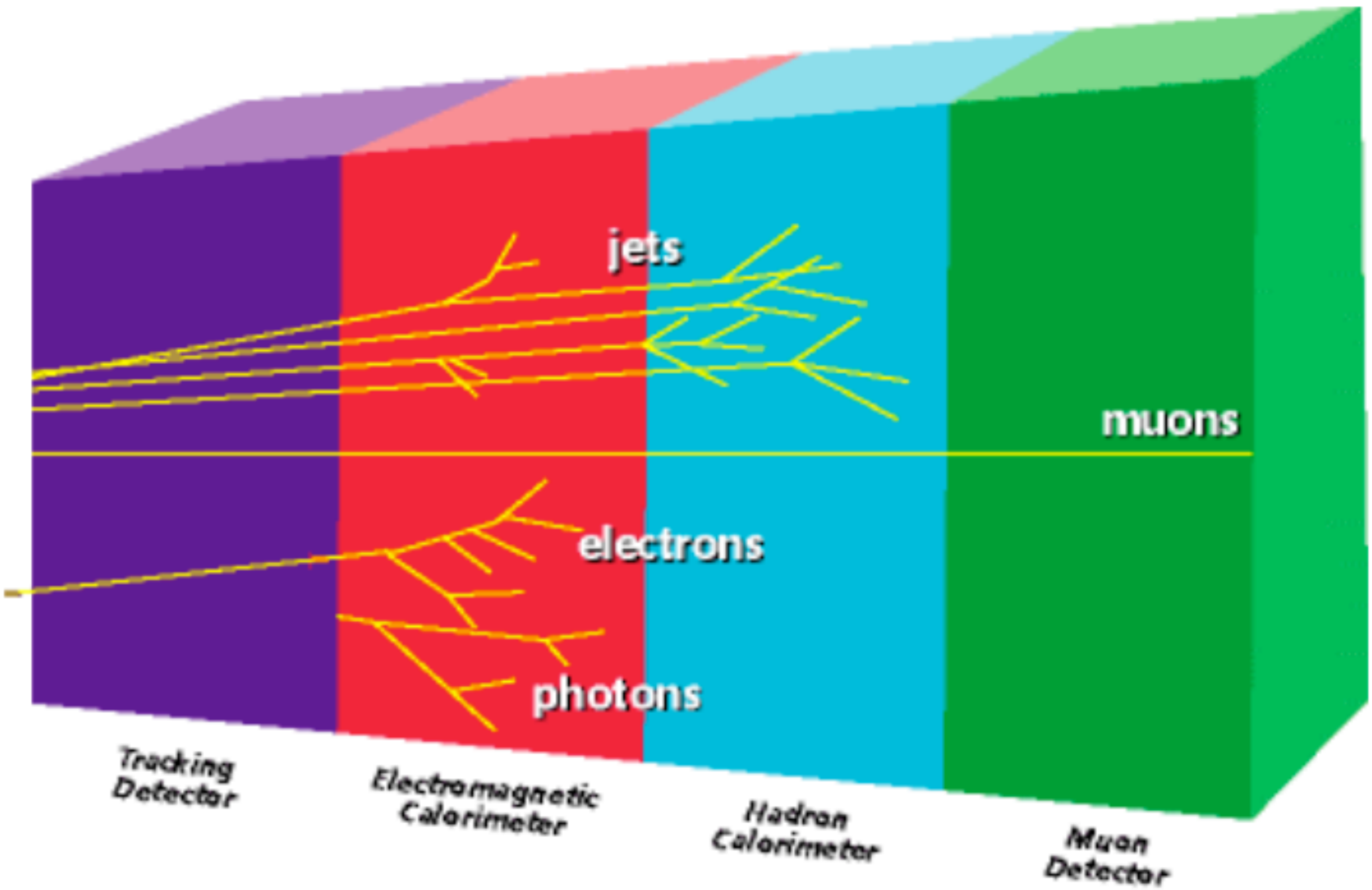
Most particles energies are absorbed by calorimeters (intermediate layers)

MIP's interact with the the most outside layers (muon chambers)

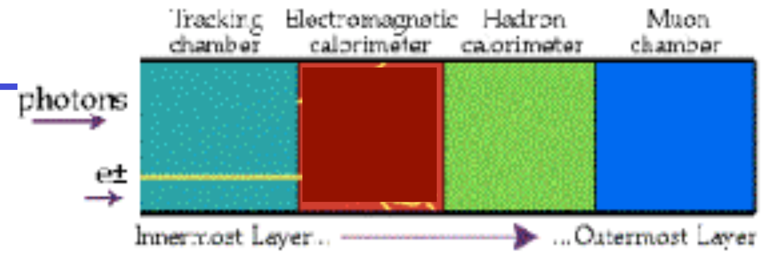
Electronics to read out each subsystem

Computers to record and analyze data

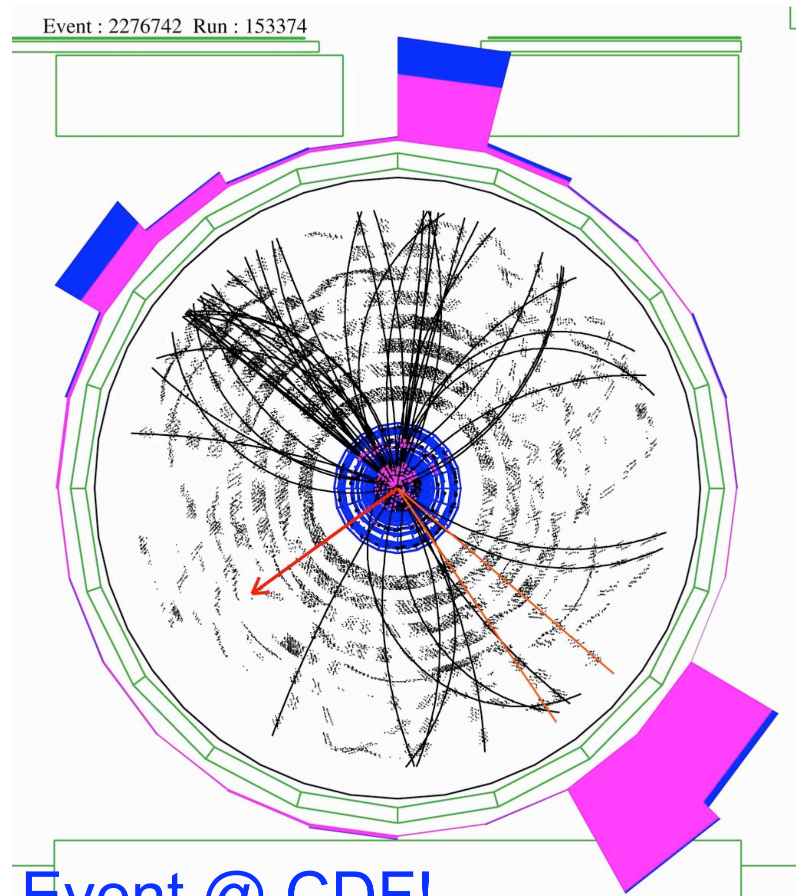
Particle In a detector



Tracks



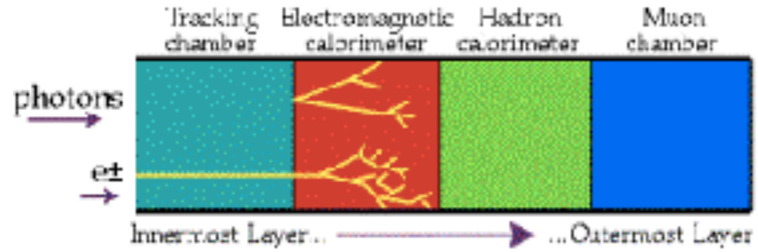
- Charged particles bend in the magnetic field
- Ions and e's knocked off gas molecules drift to the wires giving electronic signals (drift chambers)
- Hit patterns can be recognized as tracks
- The higher the energy (momentum) the straighter is the track
- Beside momentum, tracks give information about the collision point

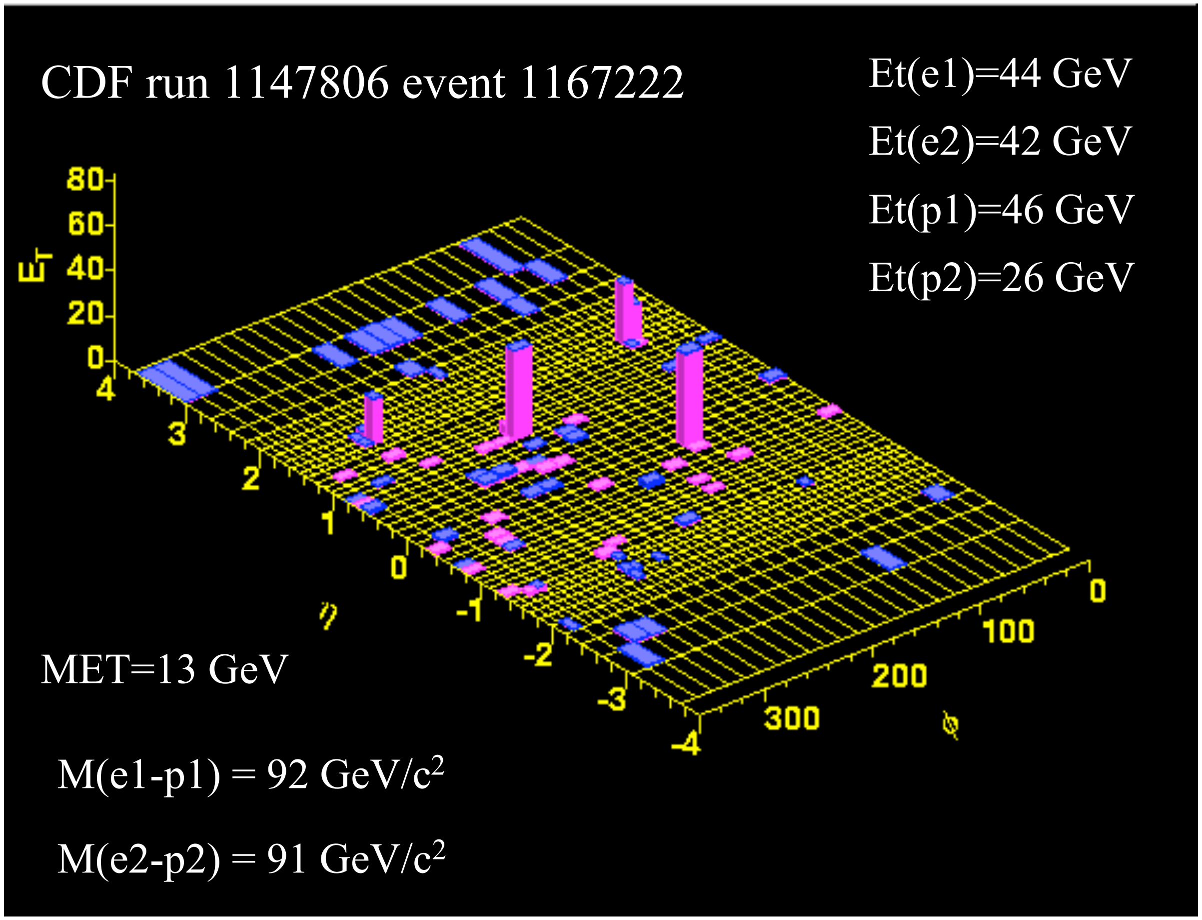


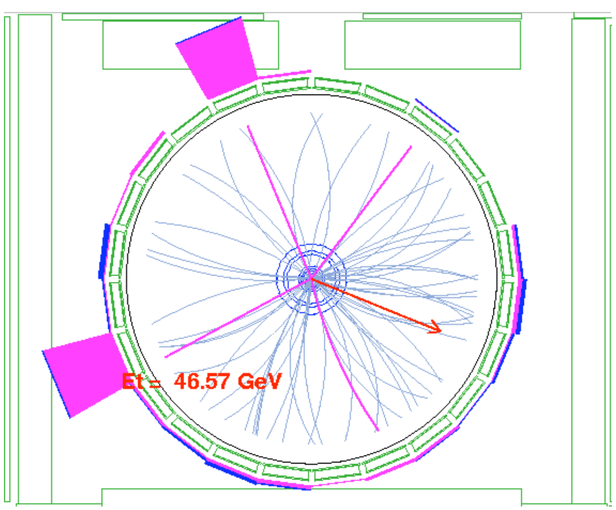
A Top Event @ CDF!

Electrons and Photons

- Electrons and Photons get easily absorbed by the calorimeter (energy deposit)
- Tracking association gives the ability to identify a charged particle: the electron.

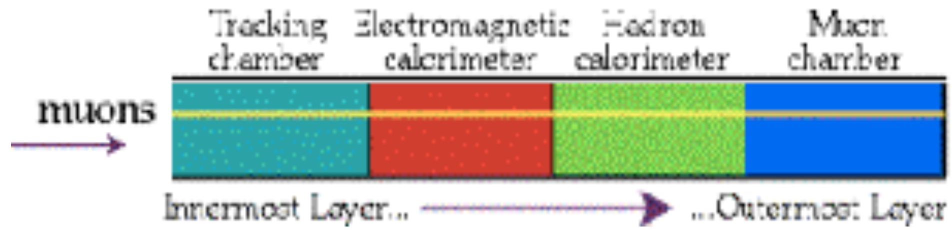






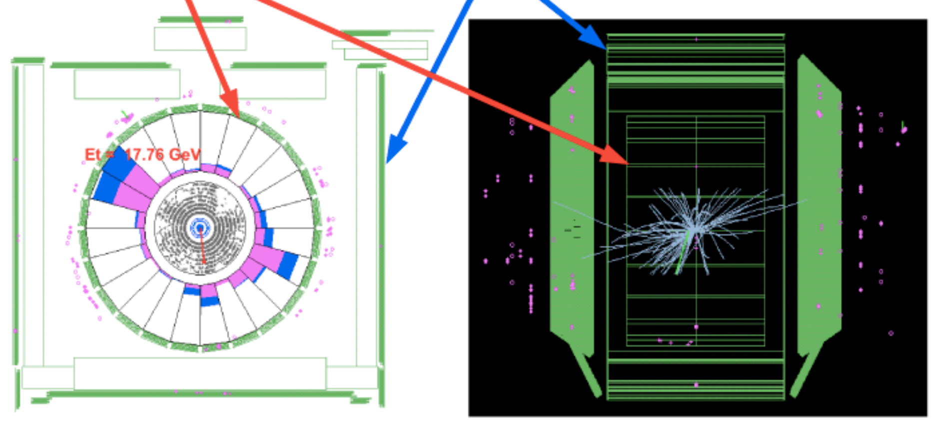
Muons

- Muons can penetrate lots of material before getting absorbed.
- Easily identified as coincidence between tracks and hits in the outer layer muon chambers: MIP

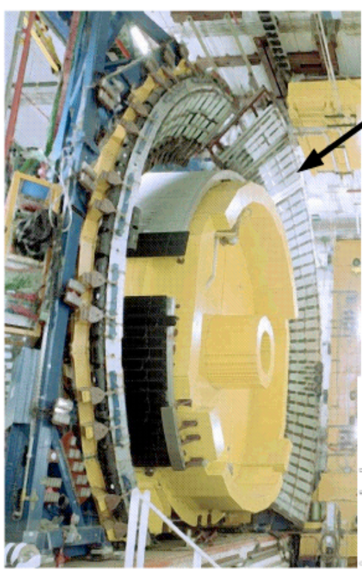


CMP
|eta| < ~0.6

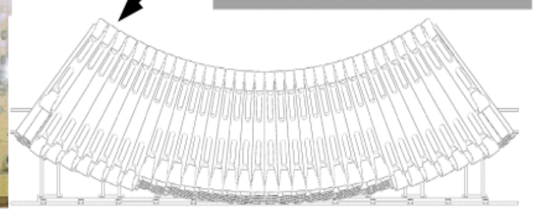
CMU
|eta| < ~0.6



CMX
0.6 < |eta| < 1.0



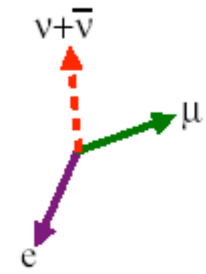
CMX Miniskirt:
Wedges 16-19

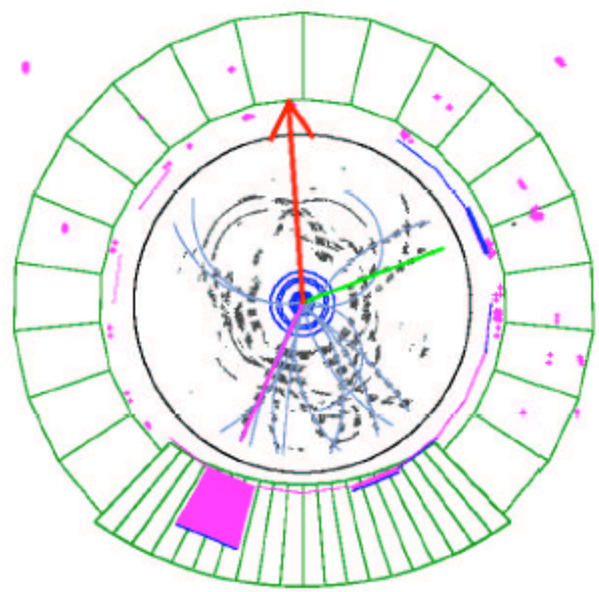


CDF Muon System

Neutrinos

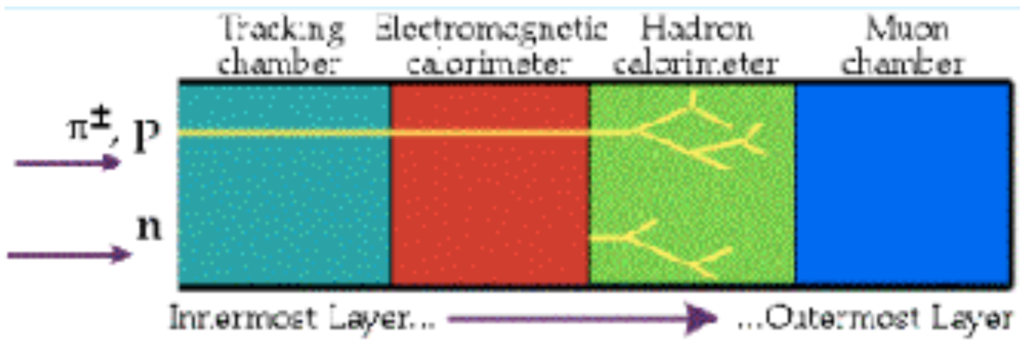
- Neutrinos rarely interact at all.
  - Since they have no charge, there is no track associated to them.
  - They don't leave energy in the calorimeter
  - They leave the detector undisturbed…
- <u>The presence of the neutrino is inferred by its absence!</u>
- We deduce the presence of neutrinos by calculating the missing energy to the total energy of the event.

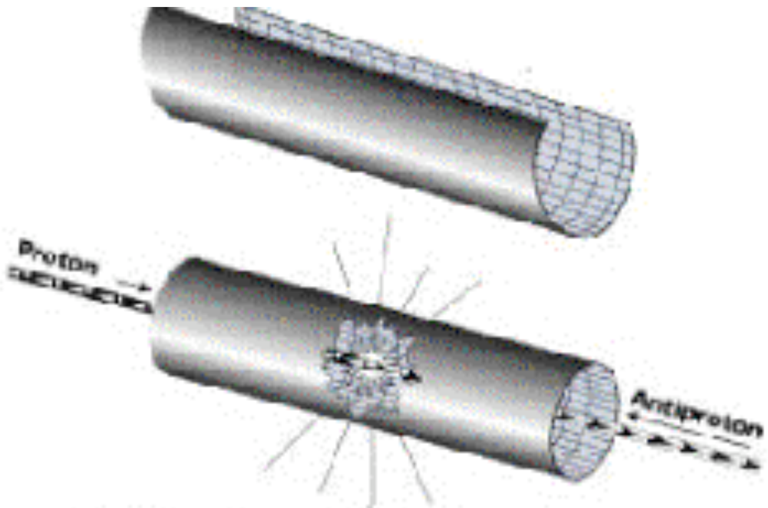


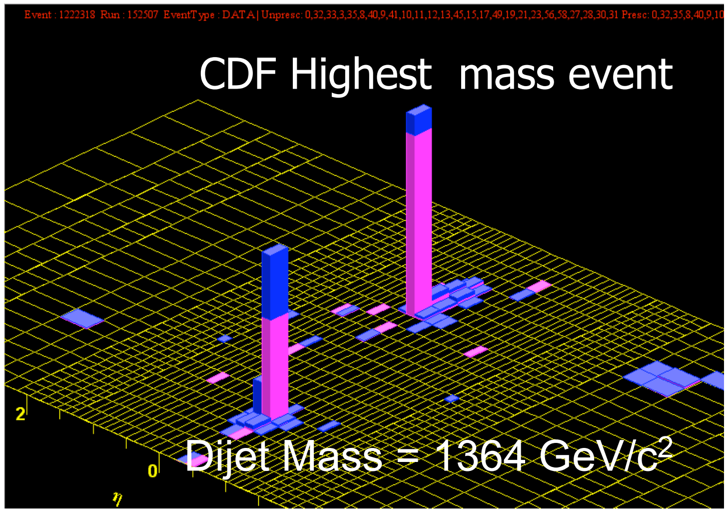


Jets

- A quark or gluon flying out of the interaction point will generate lots of hadrons moving in the same general direction: a jet.







Signatures and Physics Objects

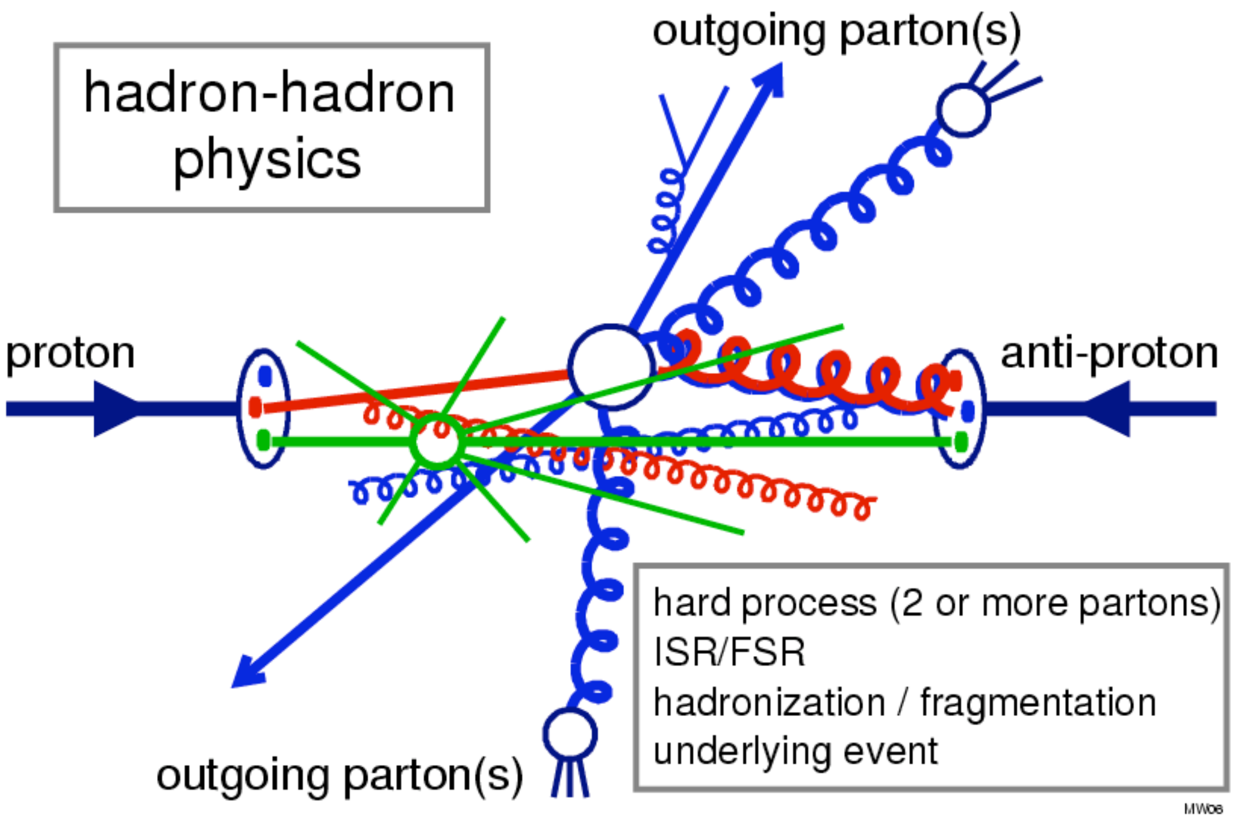
- Physics Objects
  - Tracks
  - Jets
  - Electron
  - Photons
  - Neutrinos
  - Muons

- Detector Components
  - Tracking system
    - COT
    - Silicon detector
  - Calorimeters
  - Muon Chambers

We study physics processes organizing them by their signature

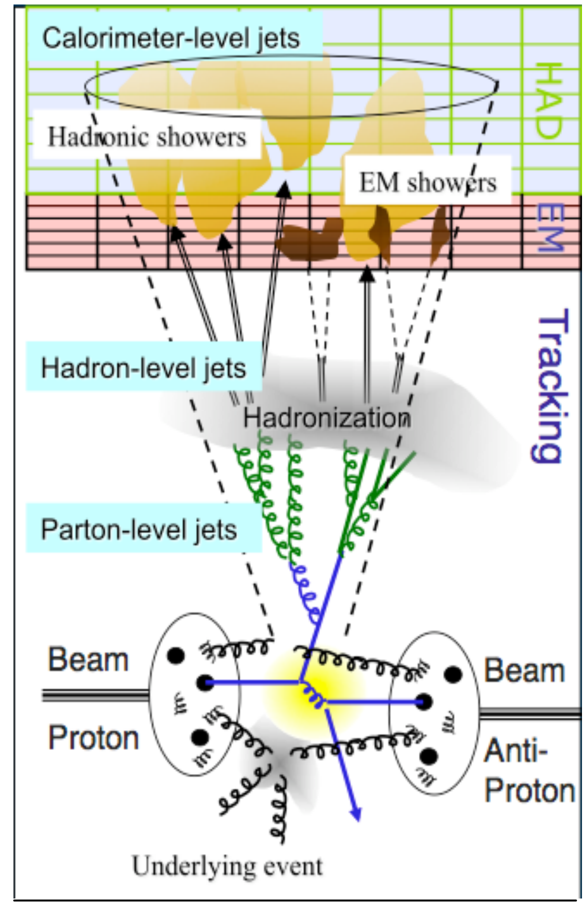
- Jets
- Leptons-only final states
  - SM and BSM
- ... + Missing Energy and Photons
  - W production
- ... + Jets and heavy flavors
  - Leptoquarks
  - Top quark

QCD at Hadron Colliders



Test of the Standard Model (pQCD)
Search for new physics
Inform/check/tune Monte Carlo and theory predictions

The tools of the trade

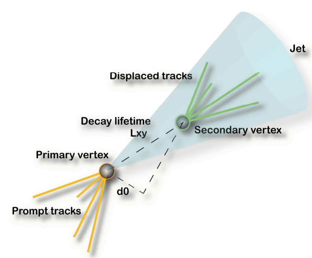


Hadronic jets are reconstructed using several algorithms: Cone,Midpoint, KT etc..

Measured jet energies are corrected to scale them back to the final state particle level jet .

Additionally there are corrections to associate the measured jet energy to the parent parton energy, so that direct comparison to the theory can be made.

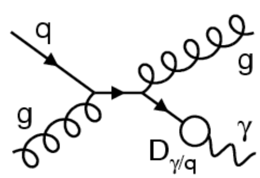
Currently the jet energy scale is the major source of uncertainty



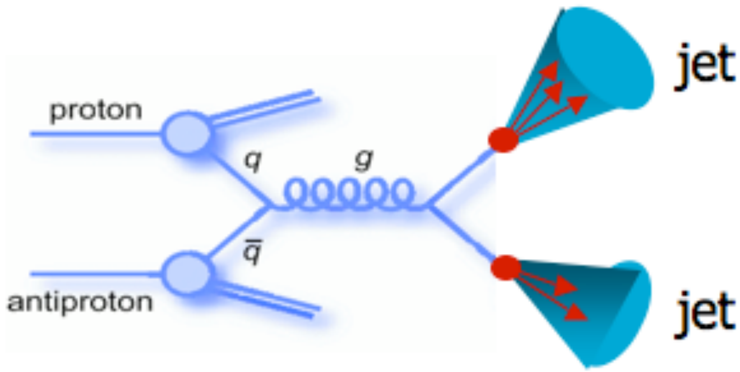
Heavy Flavor-jet identification is implemented

- -displaced vertices with L_{xy}/σ cut (CDF)
- -Vertex mass separation (CDF)
- -combining vertex properties and displaced track info with NN (D0)

Photons are selected with stringent isolation criteria to minimize fragmentation effects



Jets



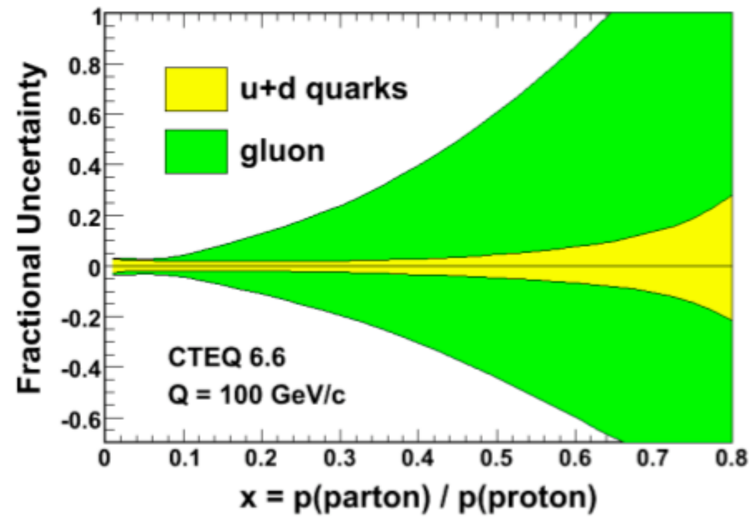
Collimated sprays of particles originating from quark and gluon fragmentation

Jets measurements probes the highest momentum transfer in particle collisions

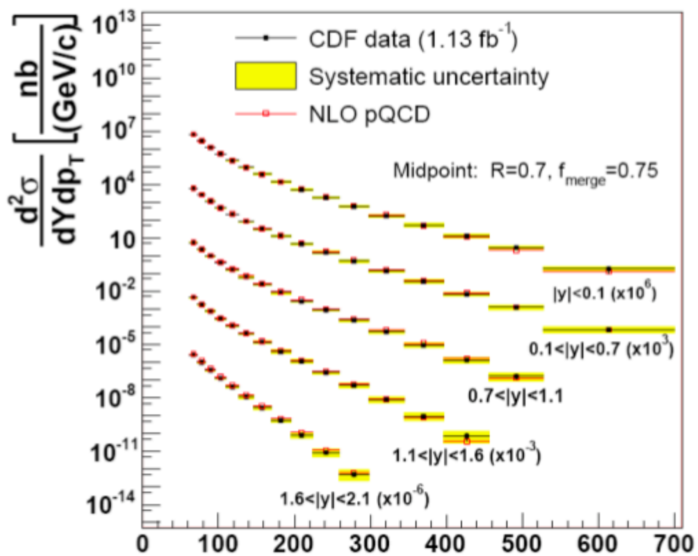
$$d\sigma_{jet} = \sum_a \sum_b \overbrace{f_{a/p}(x_1,\mu_F^2) f_{b/\bar{p}}(x_2,\mu_F^2)}^{\text{PDFs}} \otimes \underbrace{\hat{\sigma}_{a,b}(p_1,p_2,\alpha_s,Q^2/\mu_R^2,Q^2/\mu_F^2)}_{\text{Hard Scatter}}$$

Sensitive to:

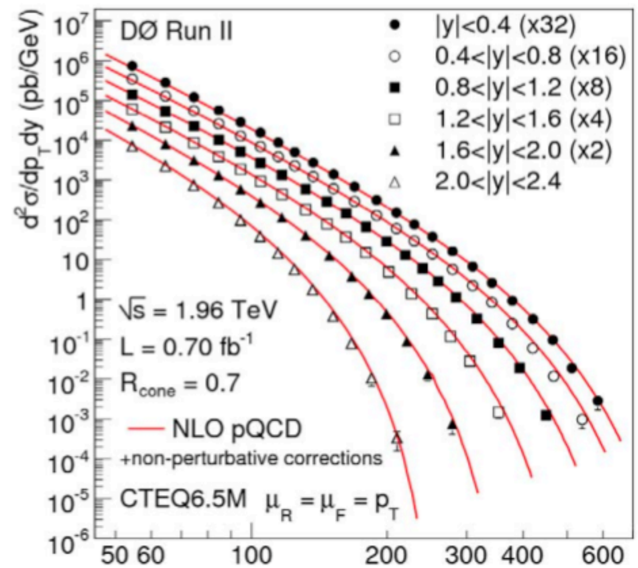
- Hard partonic scattering
- strong coupling constant
- proton's parton content
  → unique sensitivity to high-x gluon
- dynamics of interaction
  - validity of approximations (NLO, LLA, …)
  - QCD vs. new physical phenomena



Inclusive Jet Cross Section



Phys. Rev. D 78, 052006 (2008) p_T (GeV/c)



Phys. Rev. Lett. 101, 062001 (2008) p_T (GeV/c)

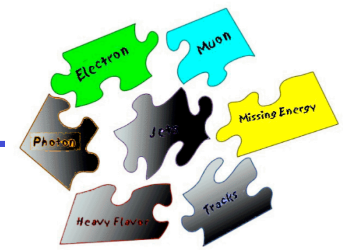
Measurements span over 8 order of magnitude in $d\sigma^2/dp_T dy$

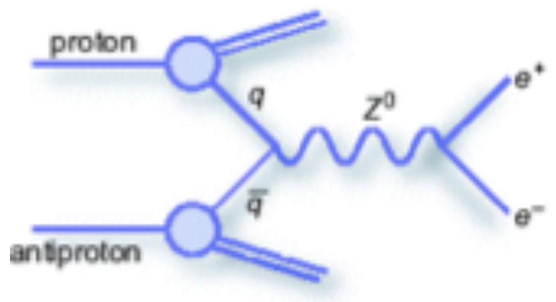
Highest p_T^{jet} > 600 GeV/c

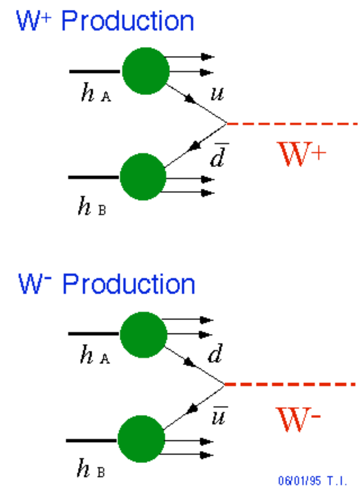
Jet energy calibration ± 1%

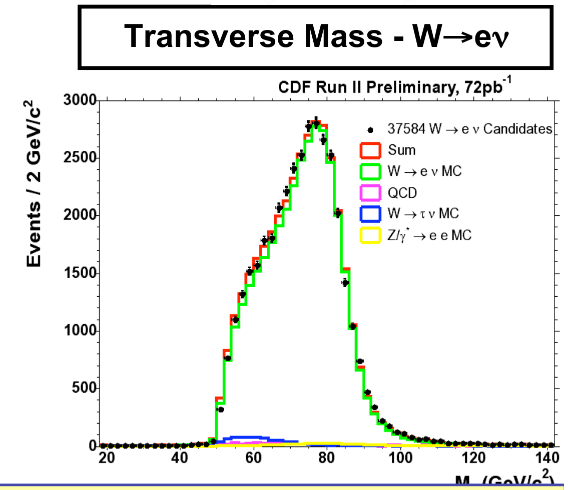
➔ ±(5 – 10)% central x-section
➔ ±(10 – 25)% forward x-section

Vector Bosons Production at CDF

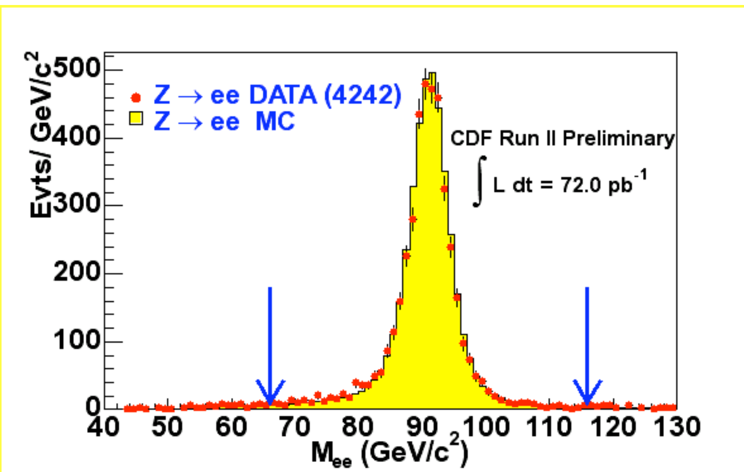








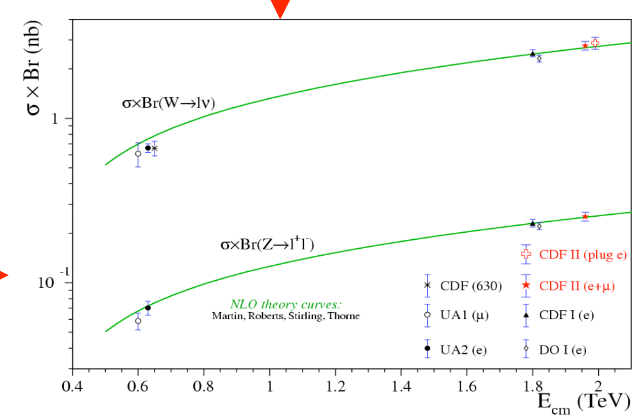
The Standard Candles



$$\sigma \cdot \mathrm{BR}(p\bar{p} \to W \to e\nu) = 2782 \pm 14(stat)^{+61}_{-56}(syst) \pm 167(lum)\,\mathrm{pb}$$

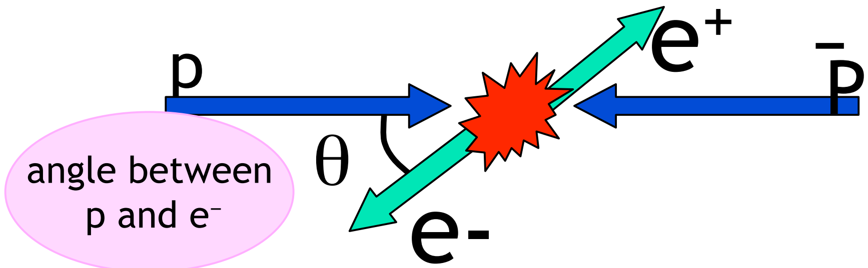
$$\sigma \cdot \mathrm{BR}(p\bar{p} \to W \to \mu\nu) = 2772 \pm 16(stat)^{+64}_{-60}(syst) \pm 166(lum)\,\mathrm{pb}$$

In agreement with previous measurements and theory prediction

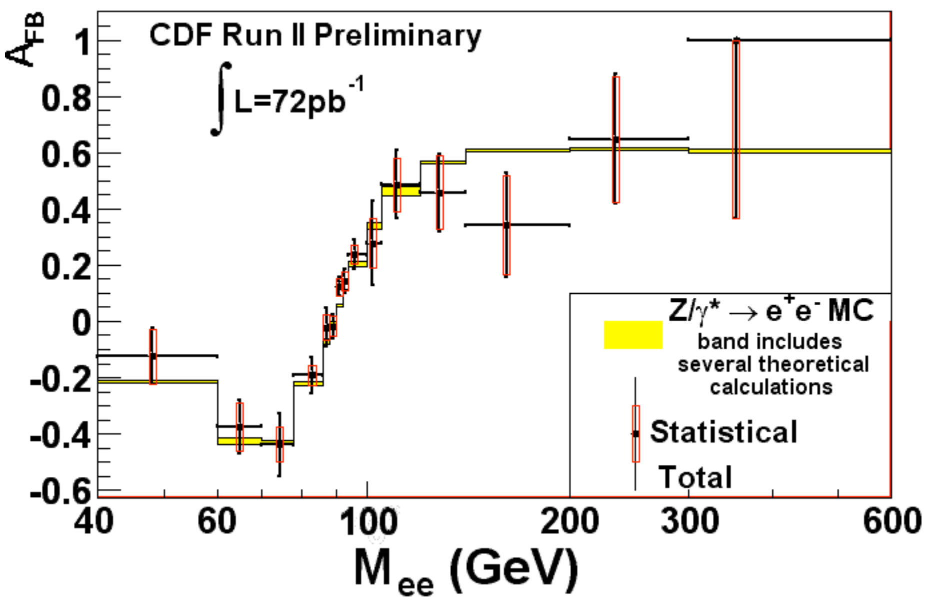


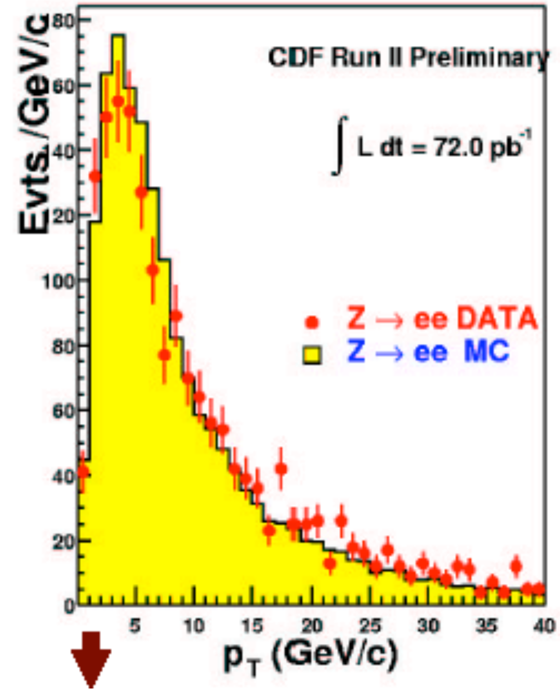
$\sigma \times BR(Z \to ee) = 255.2 \pm 3.9(stat) \pm 5.5(sys) \pm 15.3(lum)$ pb
$\sigma \times BR(Z \to \mu\mu) = 248.9 \pm 5.9(stat)\ ^{+7.0}_{-6.2}(sys) \pm 14.9(lum)$ pb

Drell-Yan Measurements at CDF



$$A_{fb} = \frac{\sigma(\cos\theta > 0) - \sigma(\cos\theta < 0)}{\sigma(\cos\theta > 0) + \sigma(\cos\theta < 0)}$$



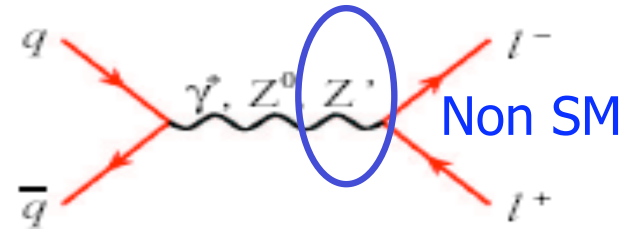


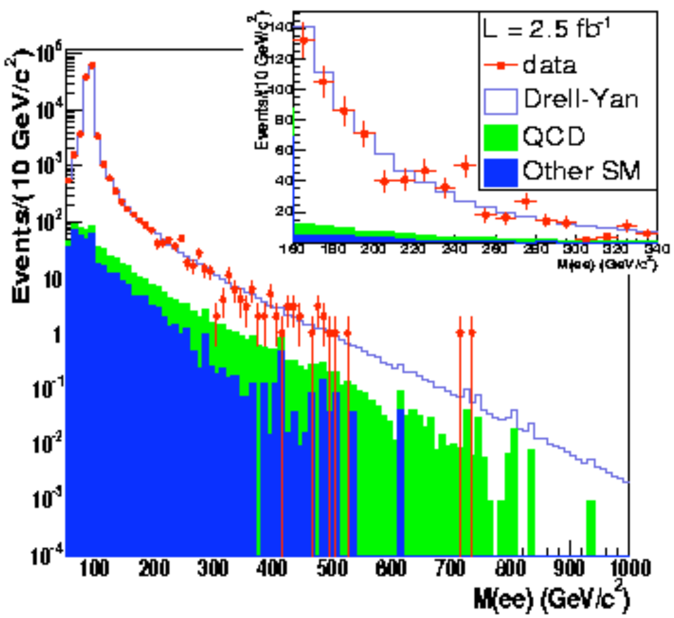
- Production properties : eventually feed into precision measurements (M_W)

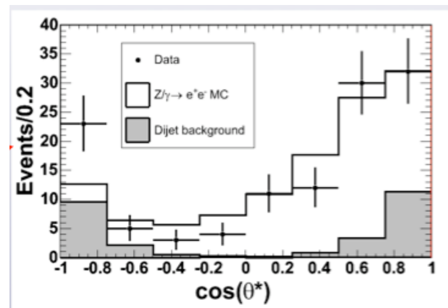
- $|\eta^e|<3.0$: using full detector coverage
- extract quark, lepton couplings & $\sin^2\vartheta_W$
- sensitive to new physics

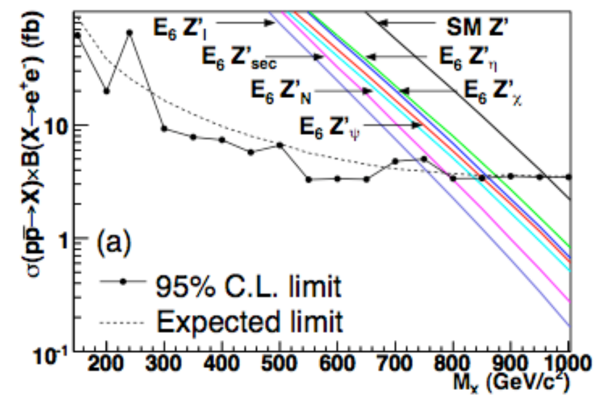
Searches for BSM using dilepton final states

Anomalous production of Z' could be seen in the dilepton mass and cosθ^* distributions (cross section enhancement)

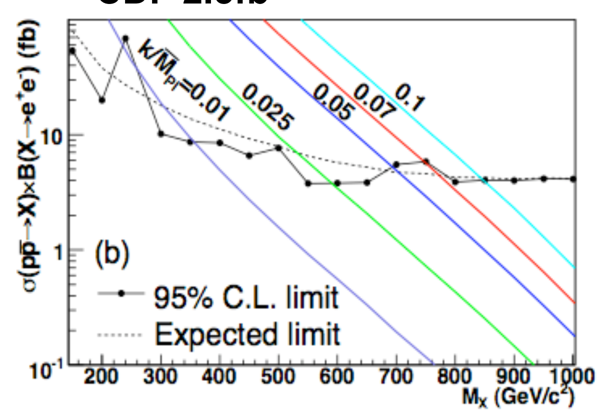








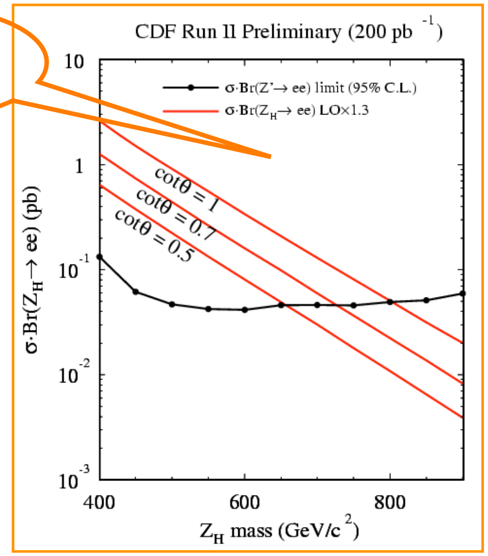
CDF 2.5fb^{-1}

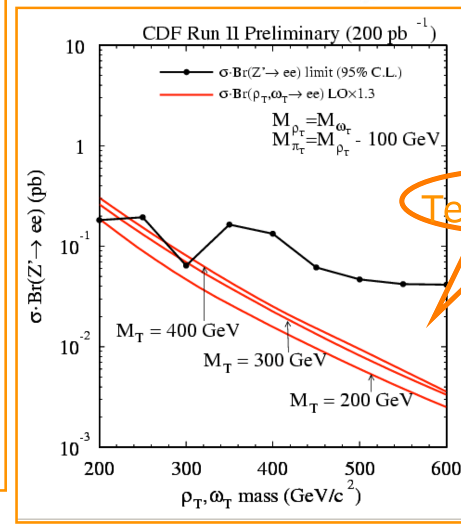


Once the data spectrum is well understood in terms of SM background, from MC, the acceptances for resonant states for different spin particles are derived (Z', RS Graviton) and the expected number of BSM events is calculated.
In the absence of an excess of data, 95% CL limits on production cross-sections and mass of the particles are set.

Searches in dileptons at CDF

Little Higgs

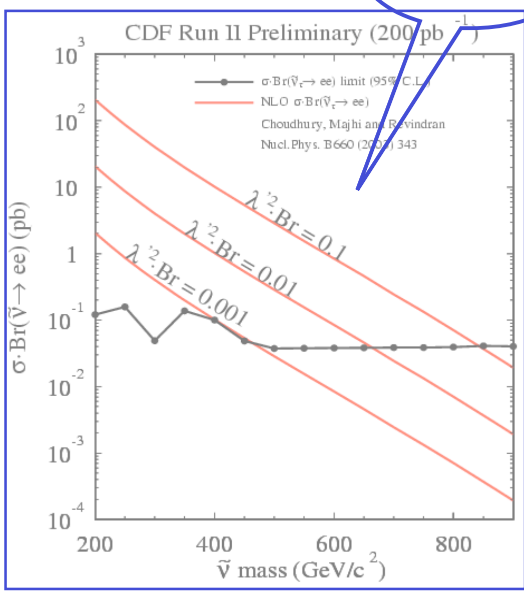


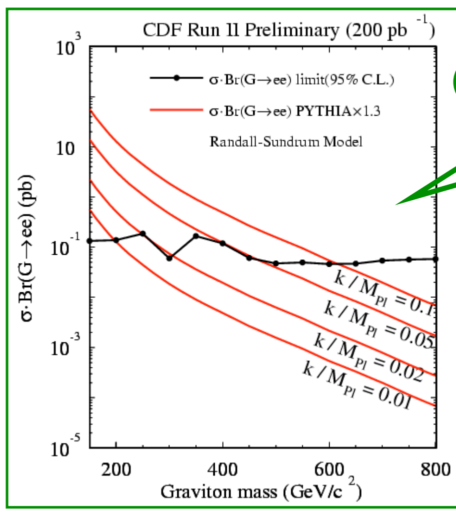


Technicolor

Calculate the acceptances for resonant states for 3 different spin assumption (0,1,2)

SUSY





Extra-Dimensions

- Randall-Sundrum graviton model

  4-dimensional metric multiplied by *warp* factor exponentially changing with the additional dimension

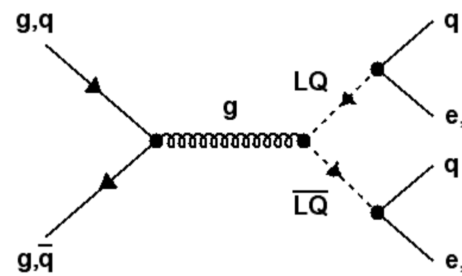
  Generating a large hierarchy does not require a large r_c

  The coupling of individual KK states to matter is set by the weak scale (parameters : M_G and $k/M_{P\,lanck}$)

  KK states can be observed as spin 2 resonances

More complex signatures: Leptoquarks

Leptoquarks (LQ) are hypothetical particles which appear in many SM extensions to explain **symmetry between leptons and quarks**
- SU(5) GUT model
- superstring-inspired models
- ‘colour’ SU(4) Pati-Salam model
- composite models
- Technicolor



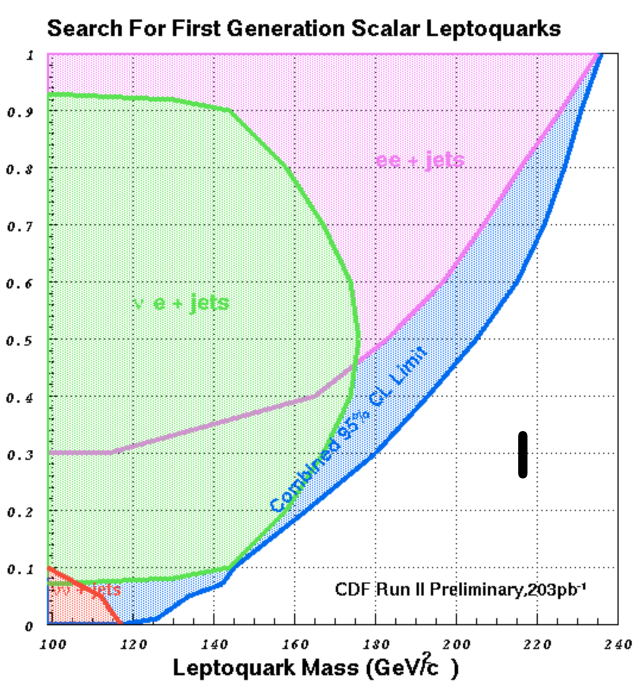
- They couple to leptons and quarks of the same generation
  - Decay is governed by Br(LQ→ql)

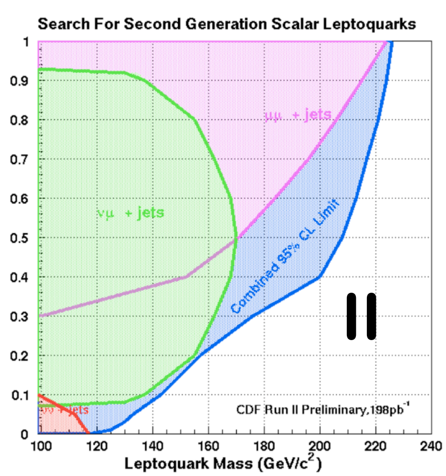
1^{st} Generation	2^{nd} Generation	3^{rd} Generation
$LQ\,\overline{LQ}\to e^-e^+ q\bar{q}$	$LQ\,\overline{LQ}\to \mu^+\mu^- q\bar{q}$	$LQ\,\overline{LQ}\to \tau^+\tau^- q\bar{q}$
$LQ\,\overline{LQ}\to e^\pm\nu_e q_i q_j$	$LQ\,\overline{LQ}\to \mu^\pm\nu_\mu q_i q_j$	$LQ\,\overline{LQ}\to \tau^\pm\nu\, q_i q_j$
$LQ\,\overline{LQ}\to \nu_e\nu_e q\bar{q}$	$LQ\,\overline{LQ}\to \nu_\mu\nu_\mu q\bar{q}$	$LQ\,\overline{LQ}\to \nu_\tau\nu_\tau q\bar{q}$

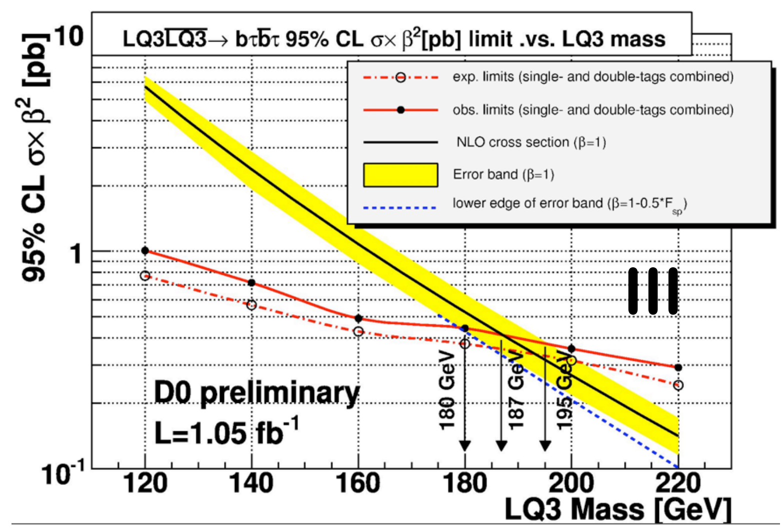
	Signature	
LQ LQ → llqq	2 leptons+2jets	BR = β^2
LQ LQ → $l\nu qq$	1 lepton+MET+2jets	BR = $2\beta\,(1-\beta)$
LQ LQ → $\nu\nu qq$	MET+2jets	BR = $(1-\beta)^2$

Search for Leptoquarks at CDF

Signature: dilepton + jets, lepton + jets + MET, MET + jets
Analysis: counting experiment
A series of cuts is applied in sequence with the goal of
reducing the background (W/Z + jets and top)
enhancing the signal retention
Cuts are optimized to give the maximum S/B
Final number of events are compared with SM expectation
No excess -> limits on production cross section

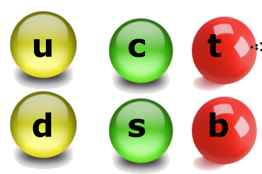






More complex signatures: The Top Quark

Discovered in 1995 at the TeVatron,
flurry of measurements still ongoing
We still don't know all about it

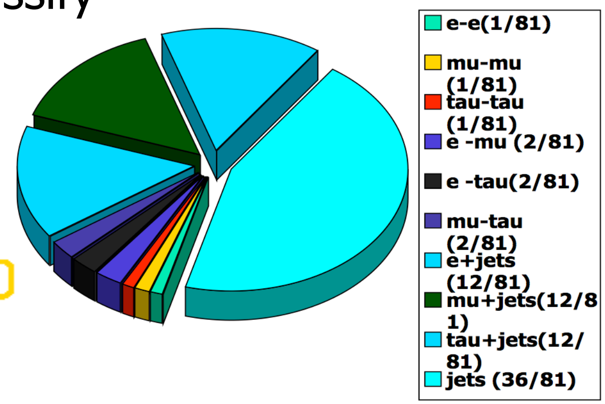


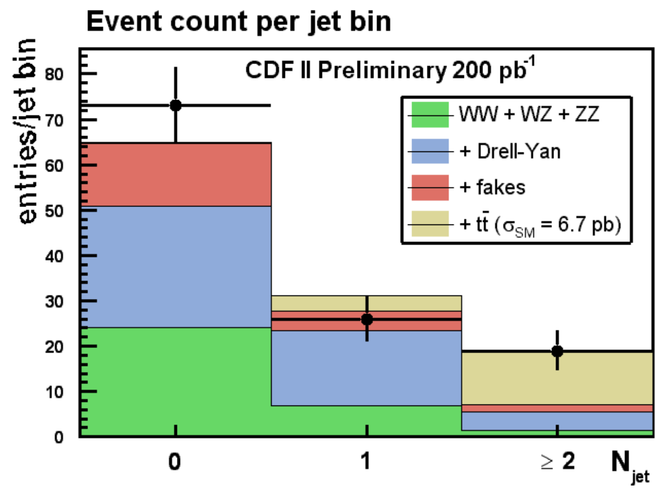
- Mass	Precision <2%
- Top width ~1.5 GeV	?
- Electric charge ⅔	-4/3 excluded @ 94% C.L. (preliminary)
- Spin ½	Not really tested – spin correlations
- BR($t \rightarrow Wb$) ~ 100%	At 20% level in 3 generations case
	FCNC: probed at the 10% level
- Production mechanisms	Single Top : just observed

The LHC will offer opportunity for further testing
and <u>precision measurements</u>

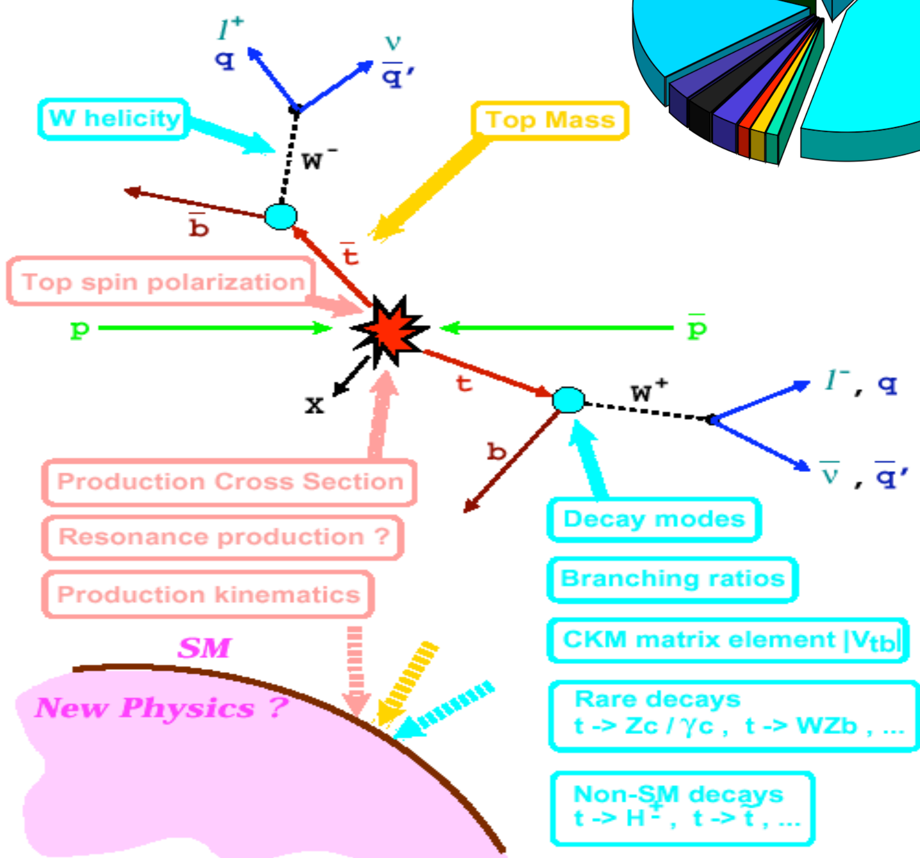
Top Quark Pair Production

Complex final state including leptons, missing energy, jets and heavy flavors
W decay mode is used to classify
the final state





Signal is well visible in ≥ 2 jets bin



A host of measurements

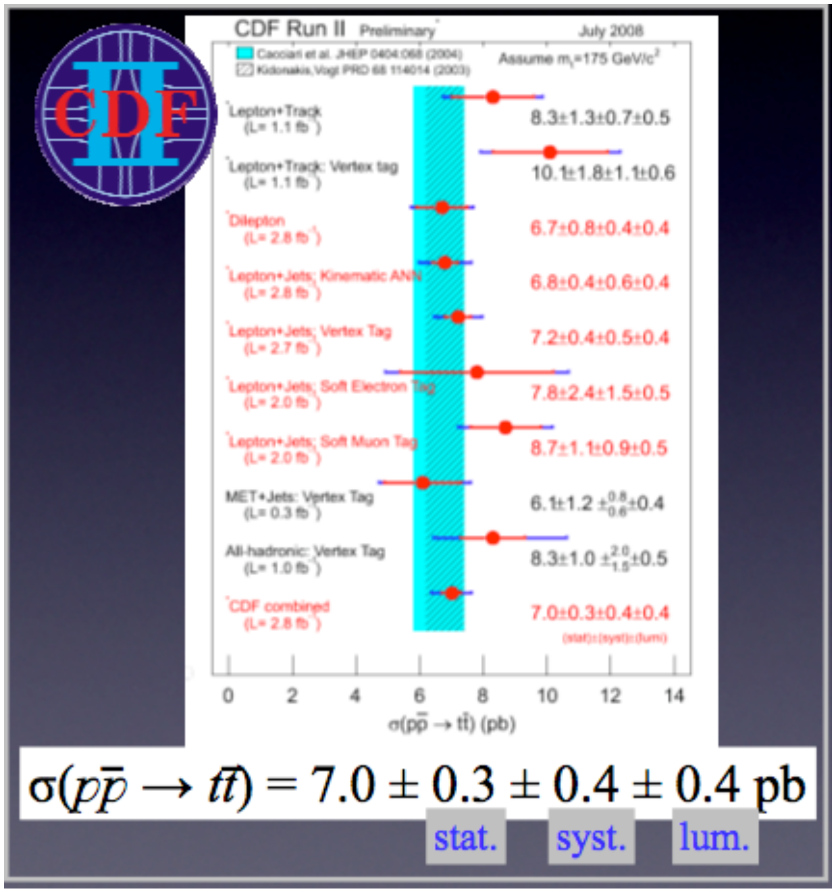
- -Mass and CrossSection
- -Wtb coupling
- -Searches for $H^+ \rightarrow tb, t \rightarrow H^+ b$
- -Search for FCNC
- -Forward-backward asymmetry
- -M_{tt} distribution
- -Search for 4th generation top
- -W boson helicity

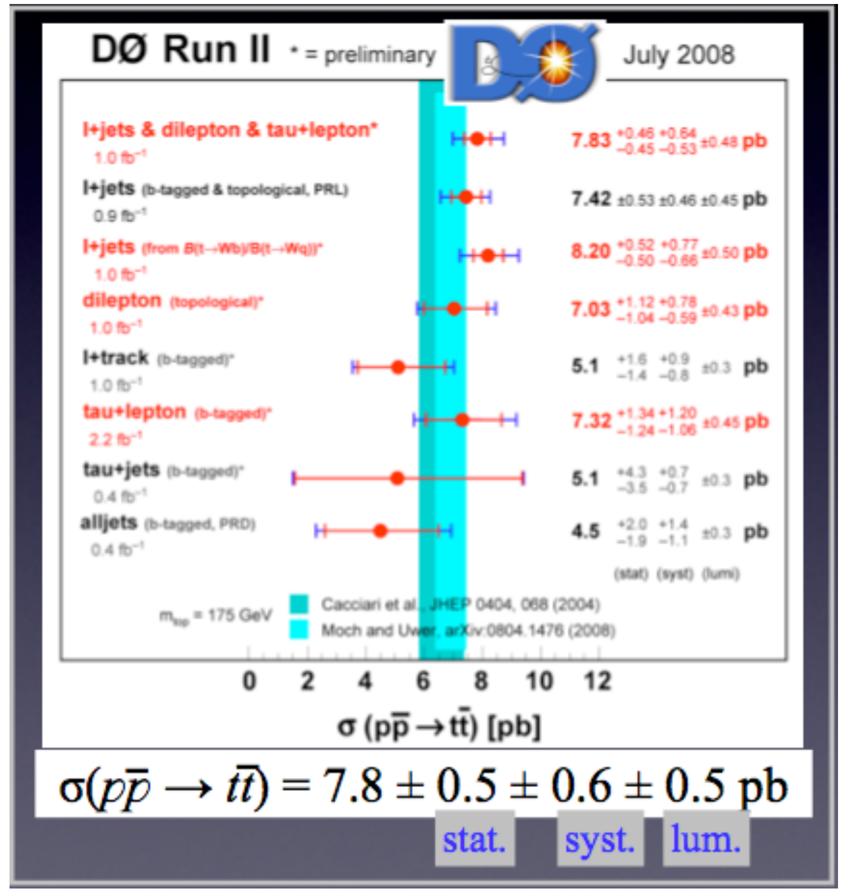
………..

Top Cross Section Measurement

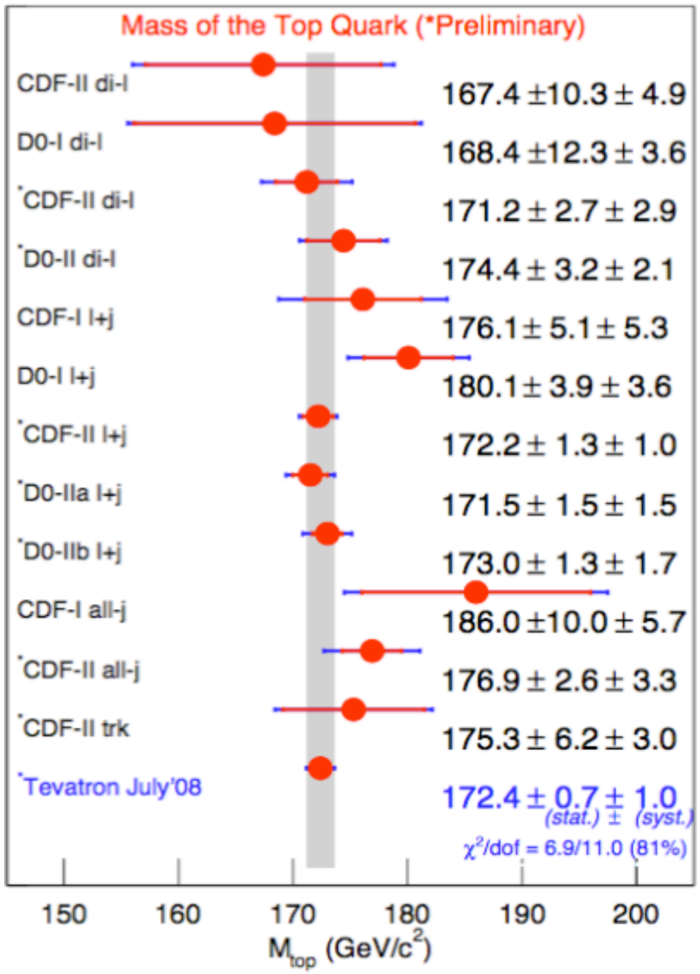
The cross section is measured in all final states: it is the first step of any study of the details of top quark properties.

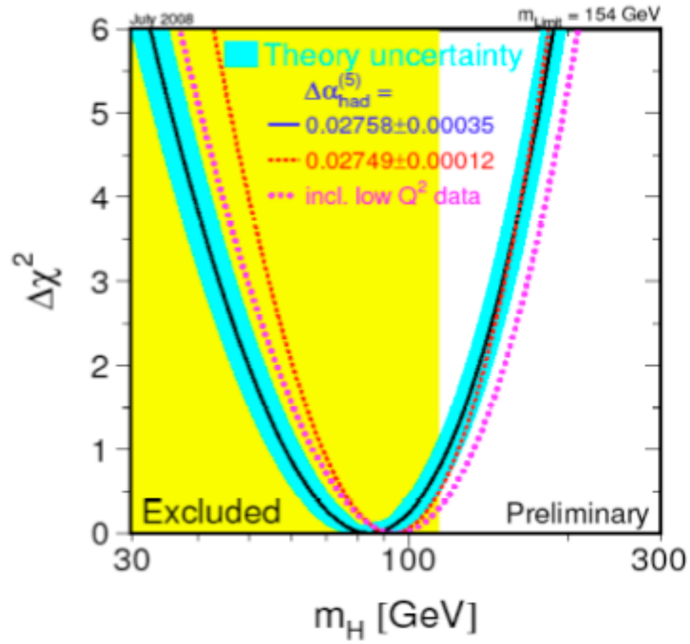
σ_{tt}=6.8±0.6 pb (Kidonakis, Vogt)
σ_{tt}=6.7+0.7-0.9 pb (Cacciari et al.)



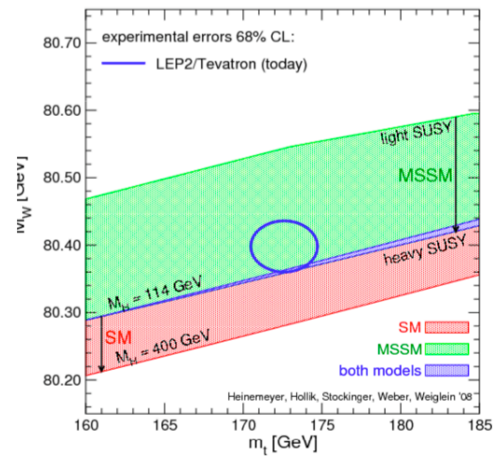


Top Mass Measurement





$m_H < 154$ GeV @ 95% C.L.



Light Higgs preferred

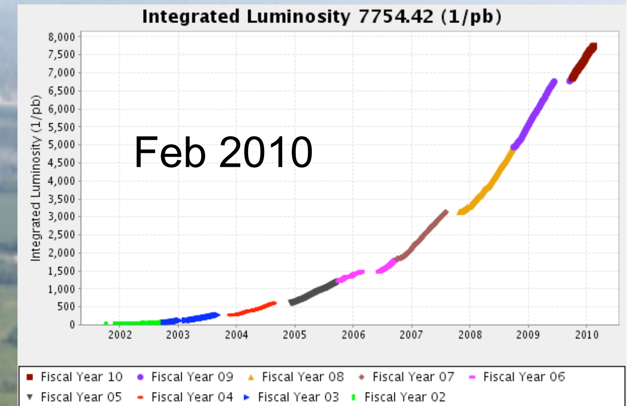
$$m_t = 172.4 \pm 0.7 \pm 1.0 \text{ GeV}$$

0.7% precision!

→ *will be a legacy to LHC for the **calibration of the jet E scale** of the Atlas and CMS detectors*

TeVatron Status

The Tavatron is the world highest energy “proton-antiproton” collider ….



- Located about 30 miles west of Chicago, IL
  - 1.96 TeV in the C.M.
- Data are continuously recorded with very high efficiency (85-90%)
- The machine and the detectors (CDF and D0) are performing very well
  - Both experiments have collected already > 6 fb-1 on tape

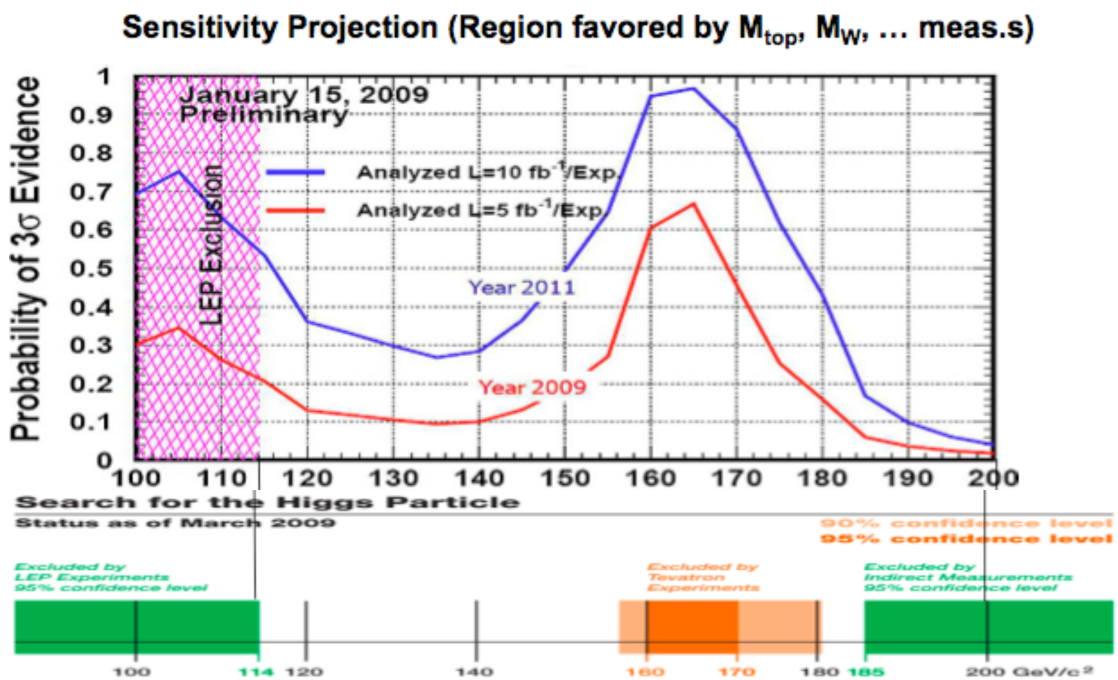
- **Measurements are becoming very precise**
  - **Top quark mass known with precision < 2%**
- **New analyses are now looking for the needle in the hay stack**
  - **low cross section phenomena**
  - **The search for Higgs**
  - **Physics beyond the Standard Model**

The Search for Higgs

In quantum field theory, the **Higgs mechanism** is the way by which the massless gauge bosons in a gauge theory acquire a mass by interacting with a background **Higgs field**.

The standard model of particle physics uses the Higgs mechanism to give all the elementary particles masses.

The Higgs particle has never been observed so far. Its mass is unknown

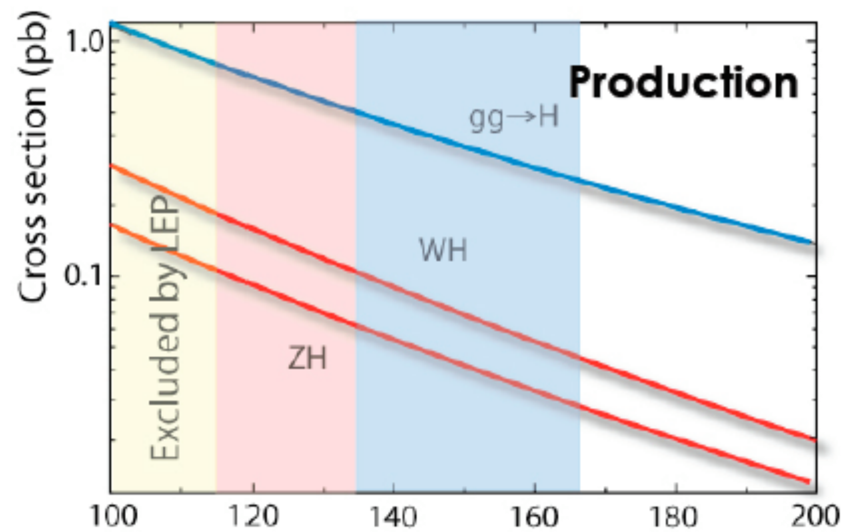


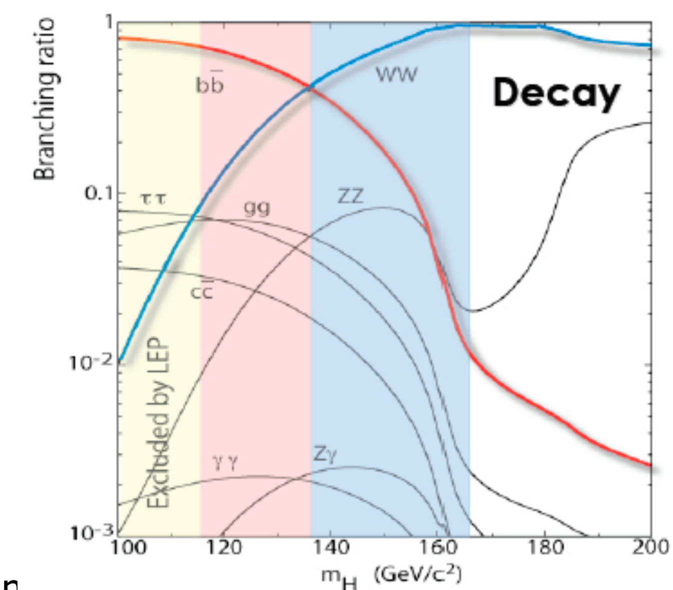
Higgs Production and Decay

<u>SM Higgs</u>

- Different production mechanisms
- Large backgrounds

- <u>Low Mass Higgs</u>
  - H→bb, QCD bb background overwhelming
  - Use associated production to reduce background
- <u>High Mass Higgs</u>
  - H→WW→lνlν decay available
  - Take advantage of large gg→H production cross section

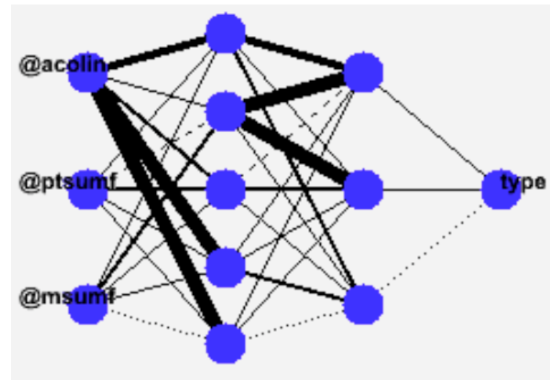




The Tools: MVA

In order to maximize sensitivity

- Neural Network (NN)
  - Well known technique.



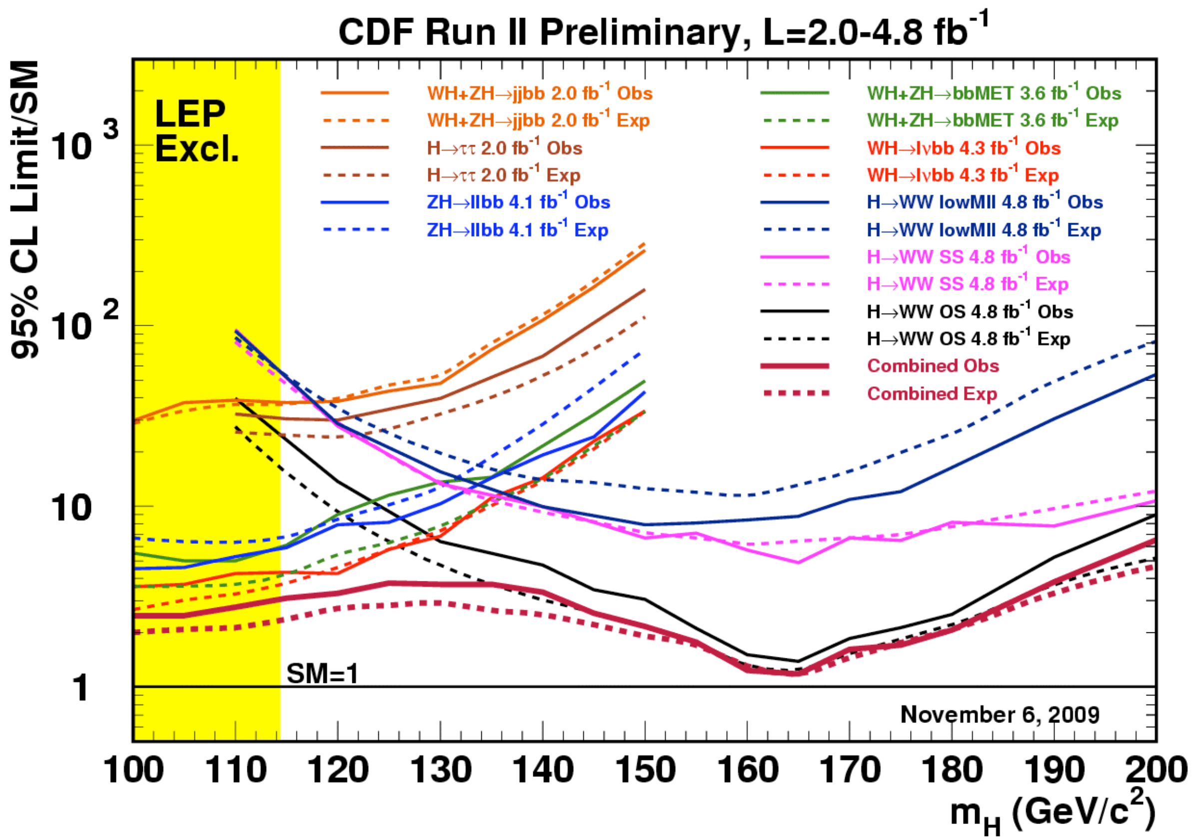
- Boosted Decision Tree (BDT)
  - Relatively new.
  - BDT is fast
    → can handle more inputs.

- Matrix Element (ME)
  - Event probability can be obtained by integrating ME.
  - Input is 4 momentum vector for each objects.
  - Need huge CPU power.

Major Inputs
- Dijet mass
- Pt of dijet
- Wpt, Zpt
- Sphericity
- $q \times \eta$
- ΔR_{jj}, $\Delta \phi_{jj}$, $\Delta \eta_{jj}$

These three approaches are often combined by Neural Net / BDT.

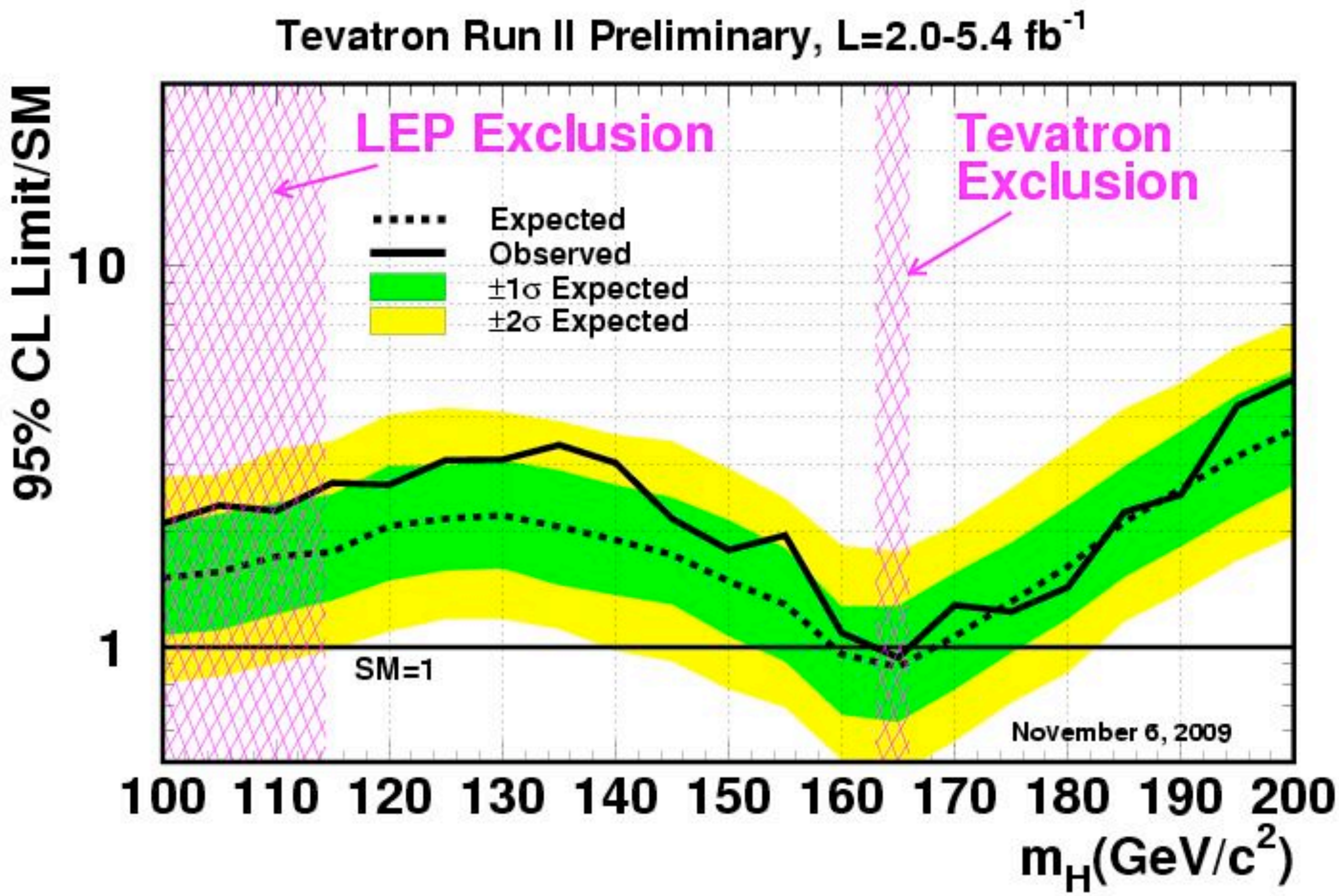
Many analyses



Both Tevatron experiments are extremely active!

m_H (GeV/c^2)	Observed limit/SM	-2σ expected	-1σ expected	median expected	$+1\sigma$ expected	$+2\sigma$ expected
100	2.58	1.02	1.38	2.01	2.81	3.92
105	2.62	1.10	1.45	2.09	2.91	4.11
110	2.88	1.10	1.54	2.14	3.06	4.43
115	3.12	1.23	1.65	2.38	3.38	4.74
120	3.37	1.37	1.92	2.72	3.87	5.43
125	3.93	1.50	2.01	2.84	4.05	5.89
130	3.80	1.49	2.02	2.92	4.16	5.80
135	3.80	1.33	1.83	2.66	3.81	5.22
140	3.53	1.24	1.75	2.51	3.60	4.95
145	2.66	1.15	1.58	2.21	3.19	4.61
150	2.26	1.02	1.38	1.92	2.86	4.05
155	1.75	0.87	1.17	1.70	2.39	3.39
160	1.23	0.69	0.90	1.31	1.84	2.44
165	1.18	0.65	0.87	1.19	1.73	2.38
170	1.60	0.77	1.03	1.45	2.06	2.97
175	1.68	0.94	1.25	1.76	2.52	3.46
180	2.09	1.08	1.52	2.08	2.95	4.22
190	3.75	1.82	2.37	3.31	4.74	6.89
200	6.52	2.38	3.36	4.66	6.64	9.30

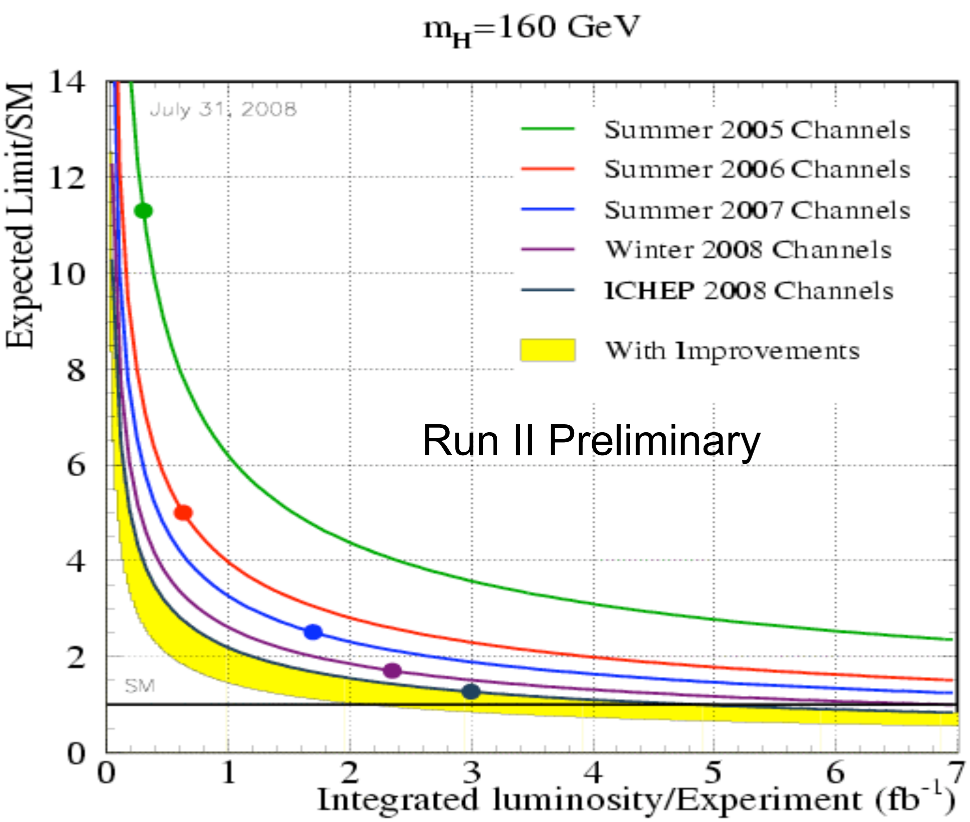
Current Exclusion Limits

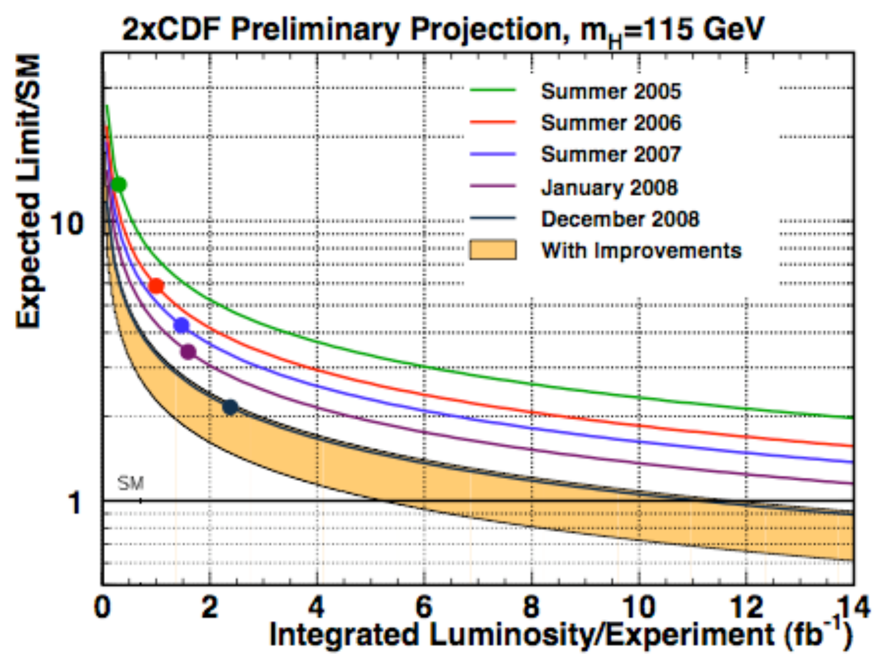


HCP 2009 Higgs Combination with L=2.0-5.4 fb^{-1} (95% C.L. exclusion for SM Higgs with mass m_H between 163 and 166 GeV/c^2)

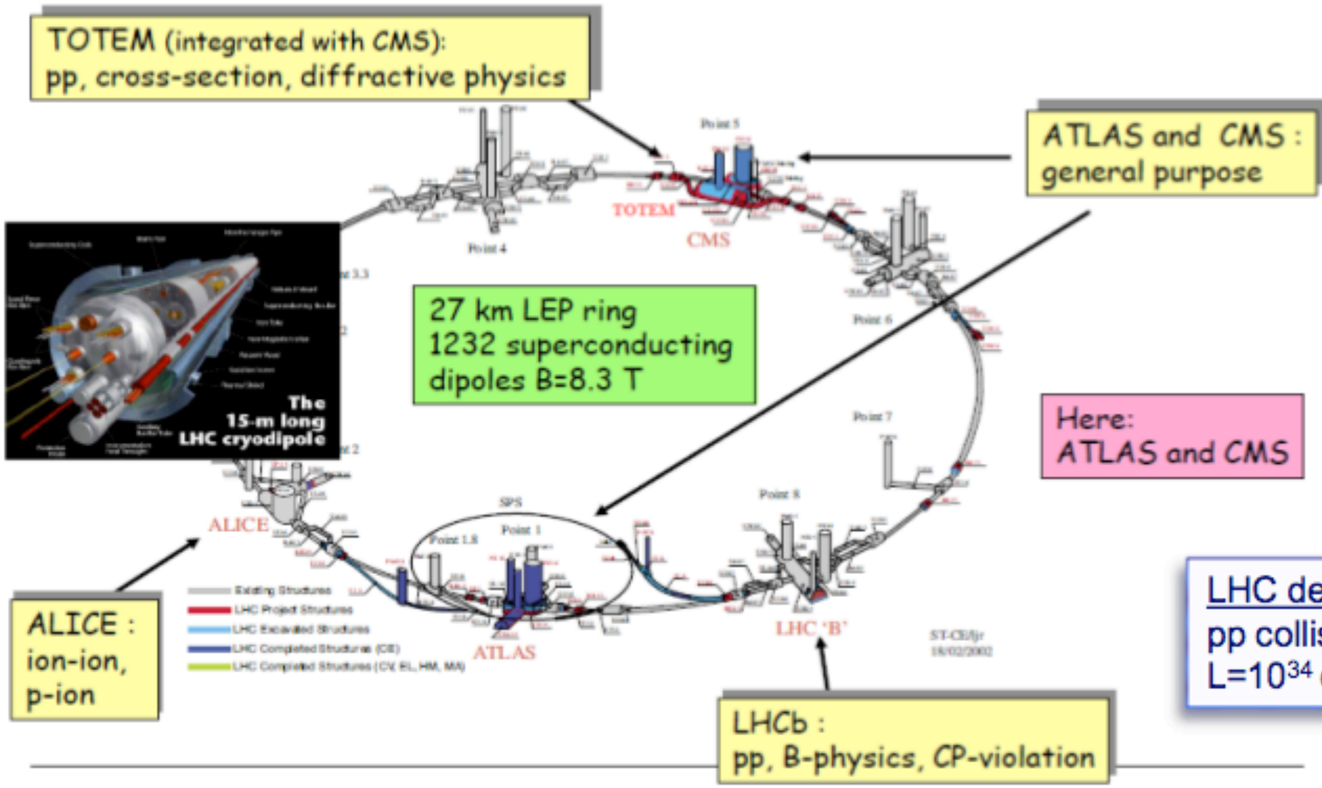
Higgs Projections at final RunII

- Goals for increased sensitivity achieved
- Expect large exclusion, or evidence, with full Tevatron dataset and further improvements.





The next frontier:LHC



<u>LHC design parameters:</u>
pp collisions at $\sqrt{s}$=14TeV
L=10^{34} $cm^{-2}s^{-1}$

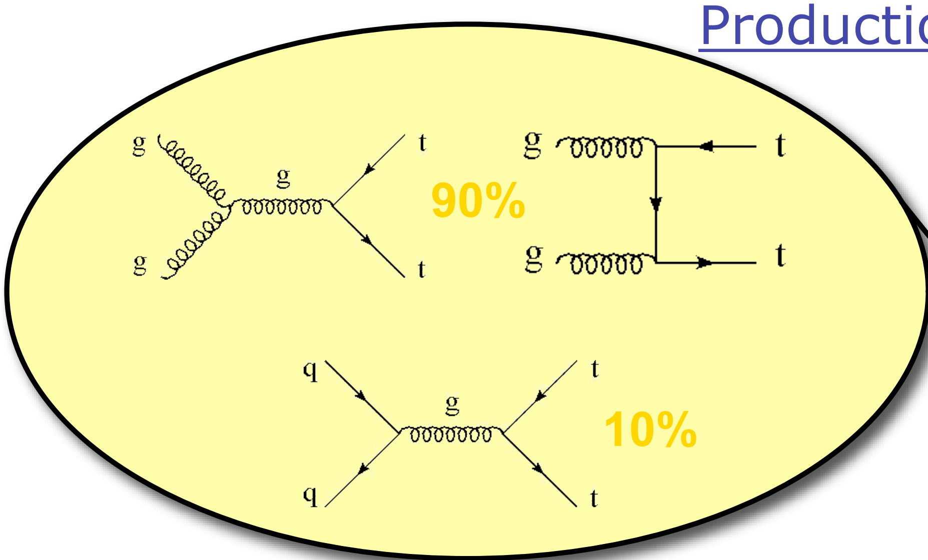
<u>LHC operations:</u>
pp collisions at $\sqrt{s}$ = 7 TeV
L = 10^{30-32} $cm^{-2}s^{-1}$

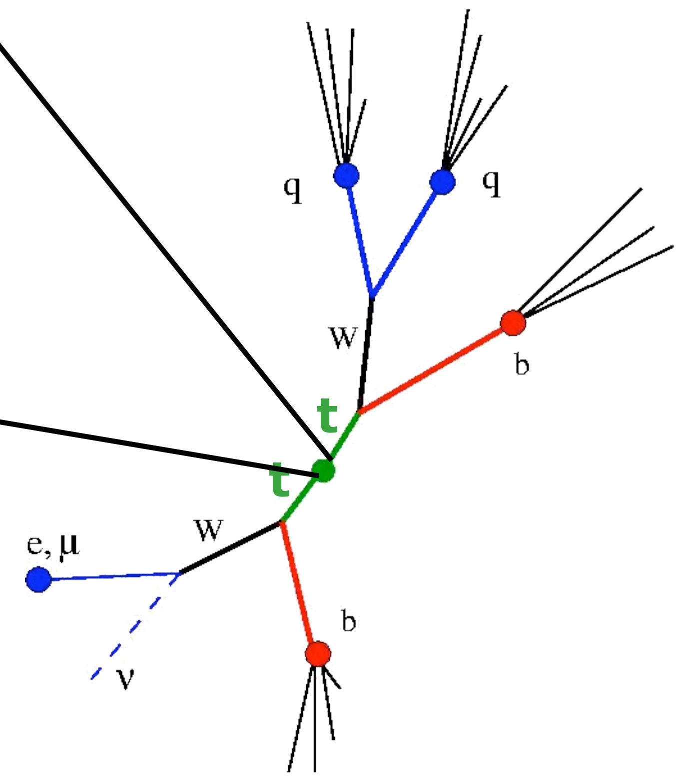
After much delay the LHC is finally starting
CM energy a factor of 2 lower than design (7 TeV) until end 2011
- Physics reach reduced

Top production at the LHC

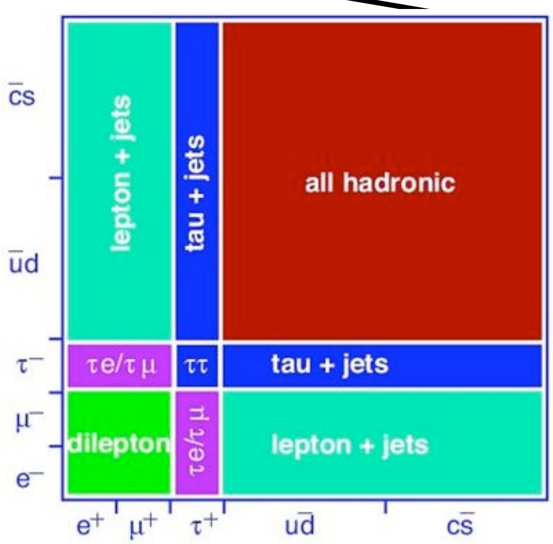
Production: σ_{tt}(LHC) ~ 830 ± 100 pb

Cross section LHC = 100 x Tevatron
Background LHC = 10 x Tevatron





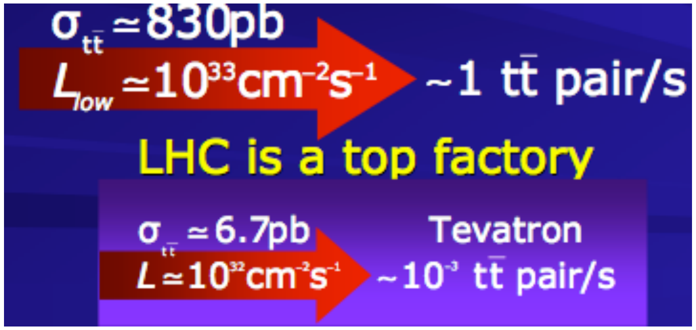
Decay



L+jets (l=e,μ) *is the Golden channel*
→ 2.5 million events/year

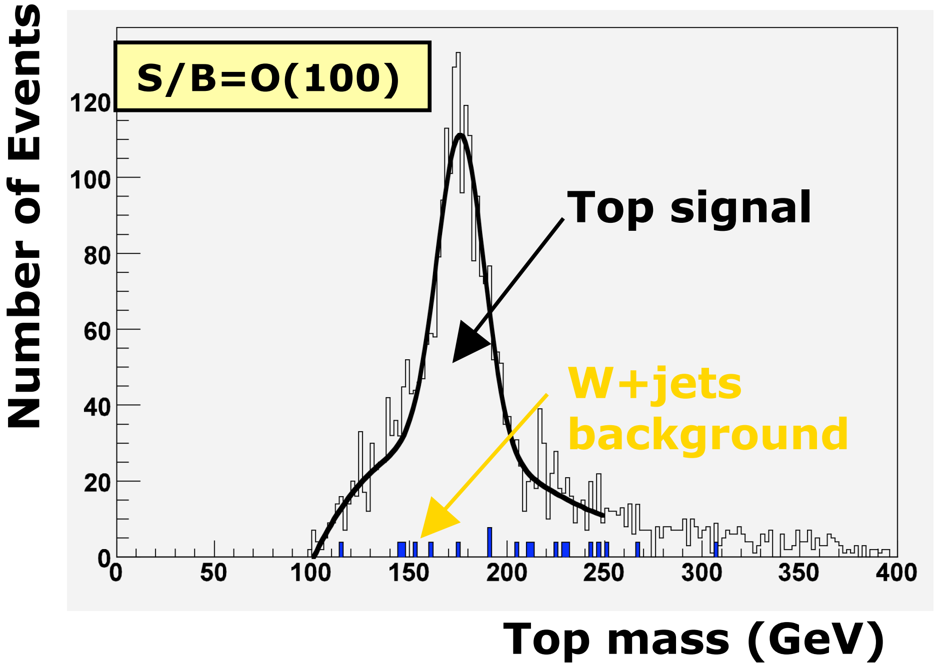
Top quark physics with b-tag at ATLAS

LHC is a top factory → Seeing top is easy



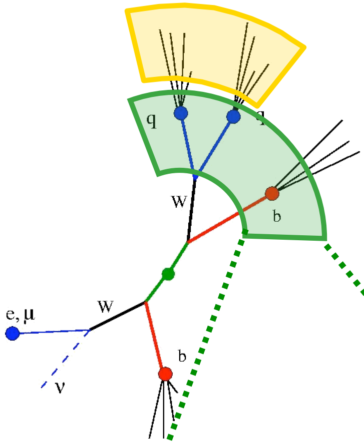
<u>Selection</u>: High P_T Lepton
Large Missing E_T
4 high-P_T jets (2 b-jets)

→ signal efficiency few %
→ *very* small SM background



- 'Standard' Top physics at the LHC:
  - b-tag is important in selection
  - Most measurements limited by systematic uncertainties
- 'Early' top physics at the LHC:
  - Cross-section measurement (~ 20%)
  - Decay properties

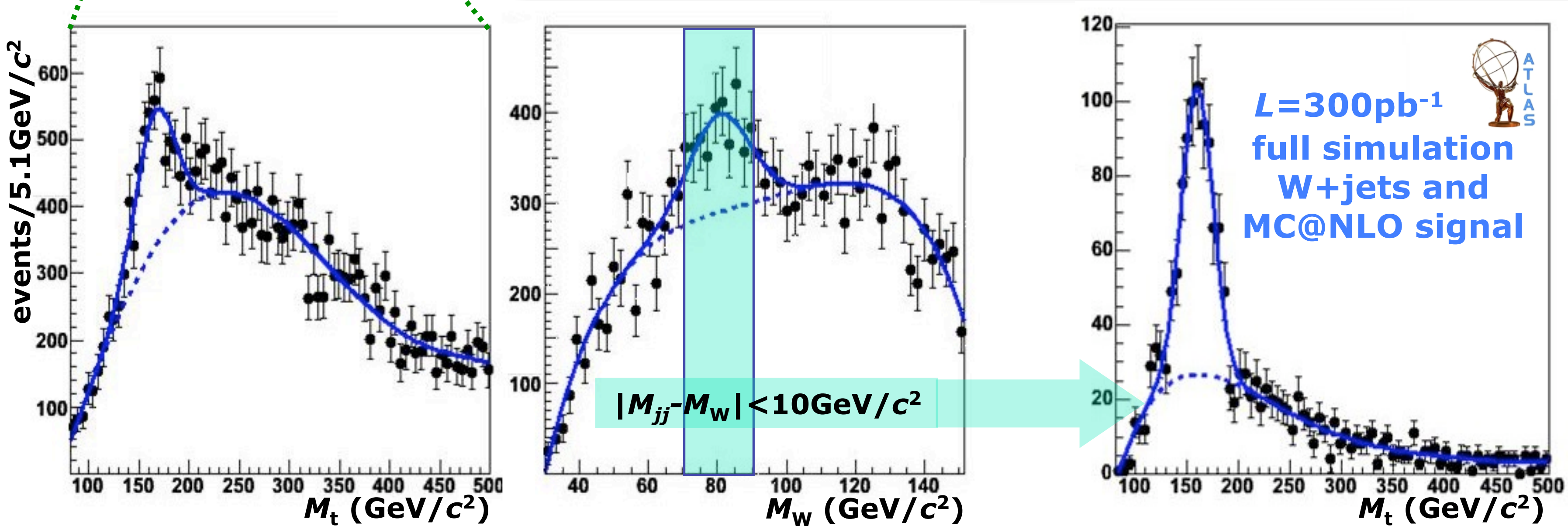
Top quark physics without b-tag (early phase)



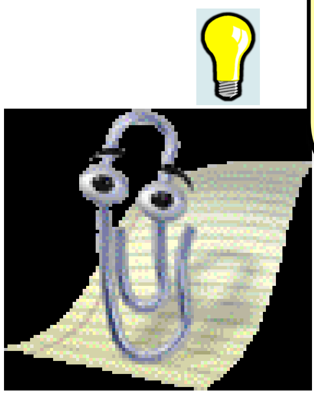
Selection

- semileptonic top: p_T(lepton)>20GeV/c, missing E_T>20GeV
  - no b-tagging required
- hadronic top: N_{jet}>4, p_T(jet)>40GeV/c (0.4 cone algorithm)
- 3 jets with highest vector-sum p_T identified as top
  - of these, 2 leading jets in 3-jet rest frame identified as W

A top peak can be seen without b-tag requirement

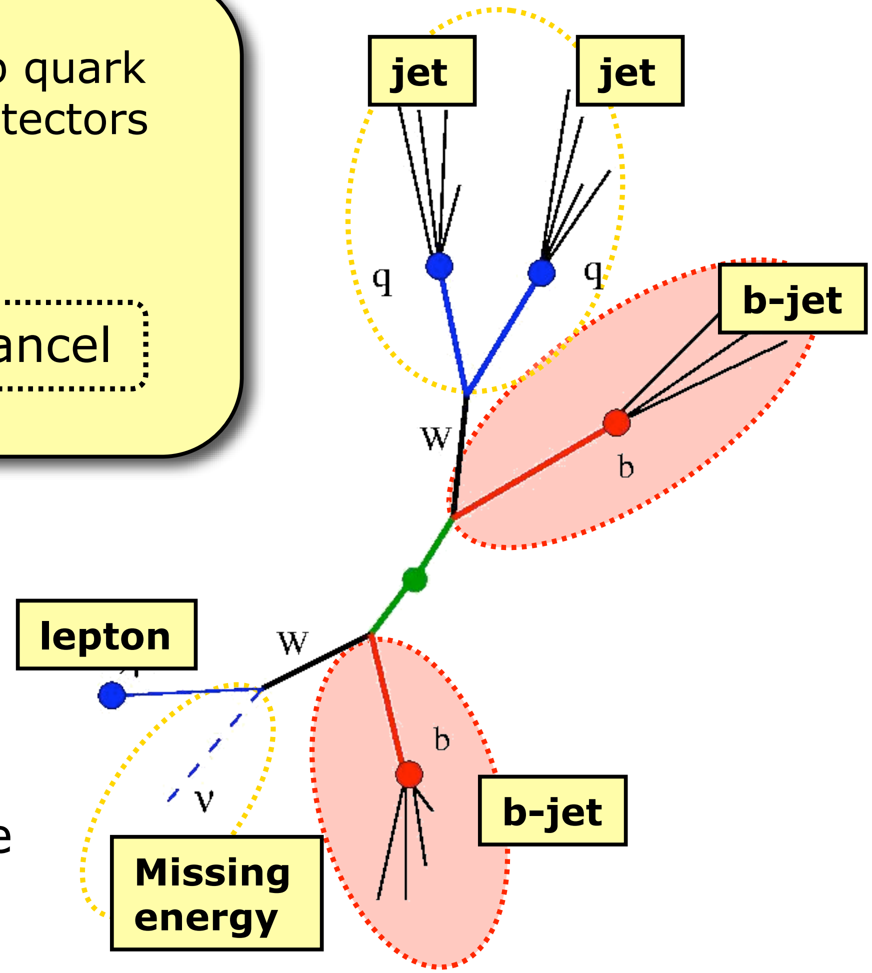


Top quark pair production as calibration tool



You can use production of top quark pairs to help calibrate LHC detectors in complex event-topologies

Yes No Cancel

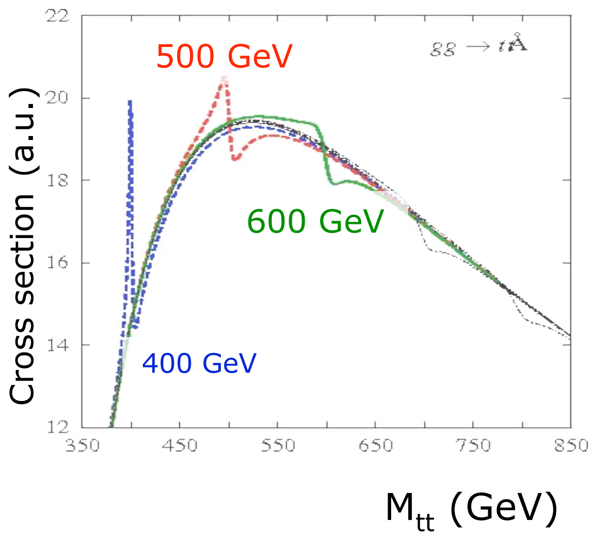


→ <u>A candle for complex topologies</u>:

- Calibrate light jet energy scale
- Calibrate missing E_T
- Obtain enriched b-jet sample
- Leptons and trigger

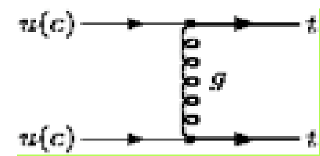
Note candles: 2 W-bosons
2 top quarks

A window to new physics ?

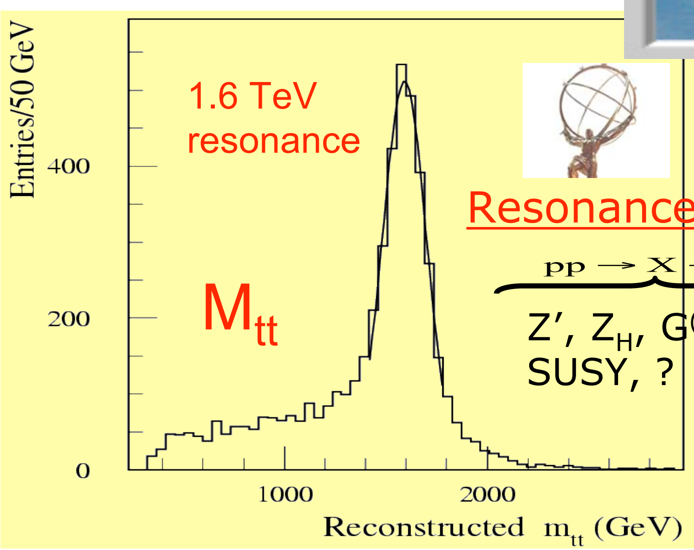


Structure in M_{tt}

Interference from MSSM Higgses H,A
→ tt (can be up to 6-7% effect)



Like-sign tt ?



Resonances in M_{tt}

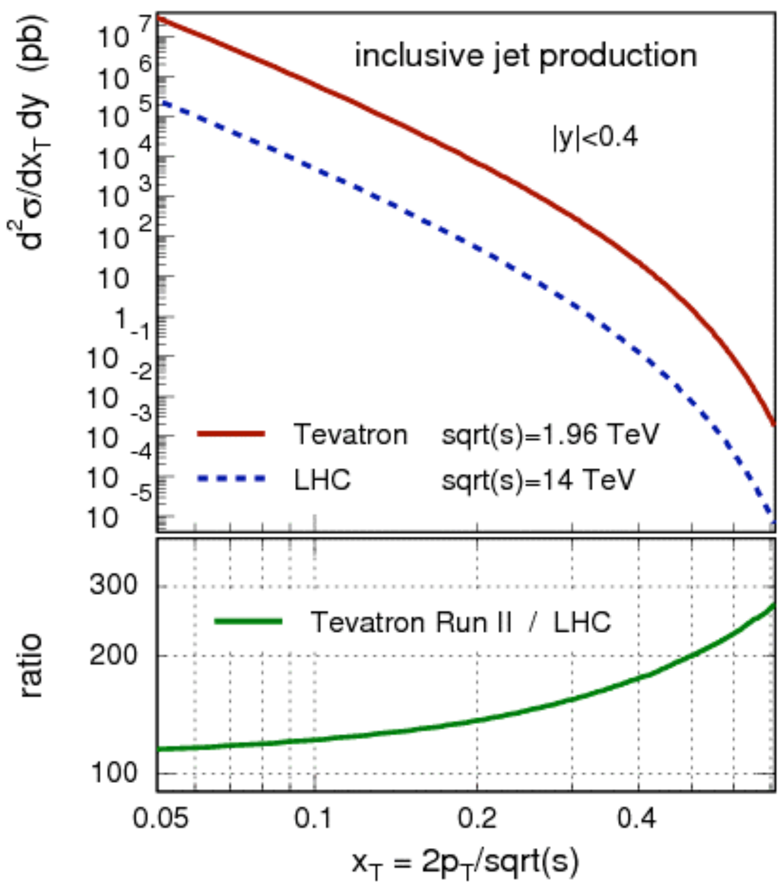
$pp \to X \to t\bar{t}$

Z', Z_H, $G^{(1)}$,
SUSY, ?

FCNC decays: GIM suppressed in SM, can be enhanced in SM extensions

q=u,c	t→Zq	t→γq	t→gq
BR(*L*=10fb^{-1})	3.4·10^{-4}	6.6·10^{-5}	1.4·10^{-3}
BR(*L*=100fb^{-1})	6.5·10^{-5}	1.8·10^{-5}	4.3·10^{-4}

LHC: Inclusive Jets



PDF sensitivity:

- → compare jet cross section at fixed $x_T = 2\ p_T$ / sqrt(s)

Tevatron (ppbar)

>100x higher cross section @ all x_T

>200x higher cross section @ x_T >0.5

LHC (pp)

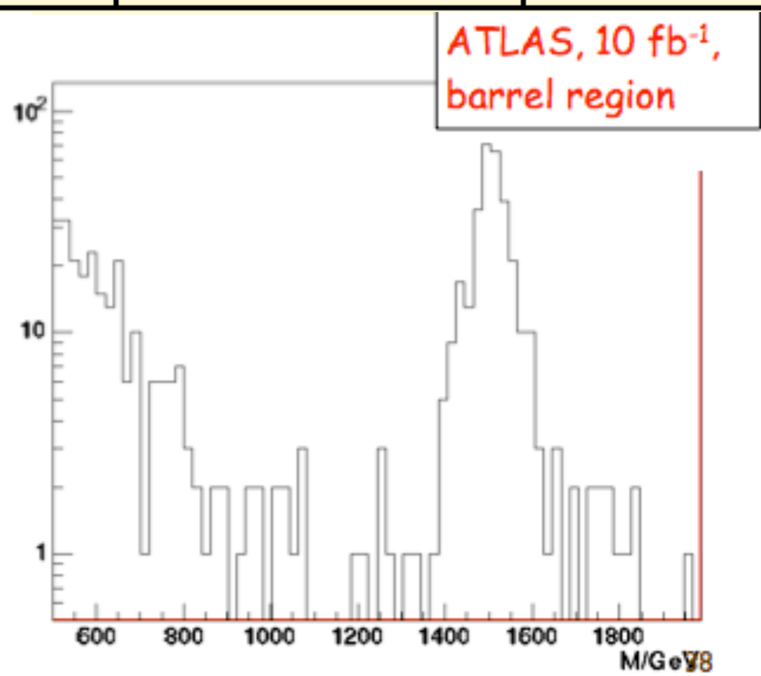
- need more than 2400 fb^{-1} luminosity to improve Tevatron@12 fb^{-1}
- more high-x gluon contributions
- but more steeply falling cross sect. at highest p_T (=larger uncertainties)
- Poorly constrained JES uncertaintyin early data impact (5-10% for jets below 1TeV) will seriously limit the physics potential of the data (D. Clements, DIS 2007).

→ Tevatron results will dominate high-x gluon for some years

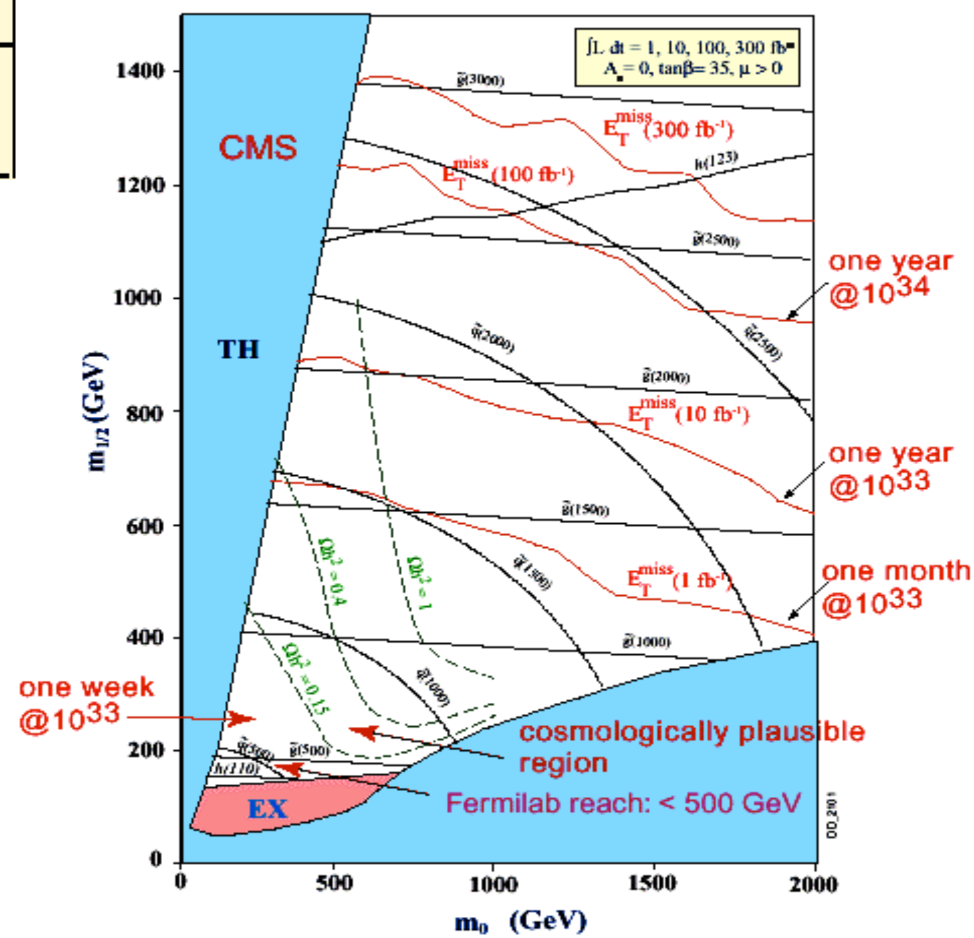
LHC: early discoveries?

$Z' \to ee$

Mass	Expected events for 10 fb^{-1} (after all cuts)	$\int L\, dt$ needed for discovery (corresponds to 10 observed evts)
1 TeV	~ 1600	~ 70 pb^{-1}
1.5 TeV	~ 300	~ 300 pb^{-1}
2 TeV	~ 70	~ 1.5 fb^{-1}

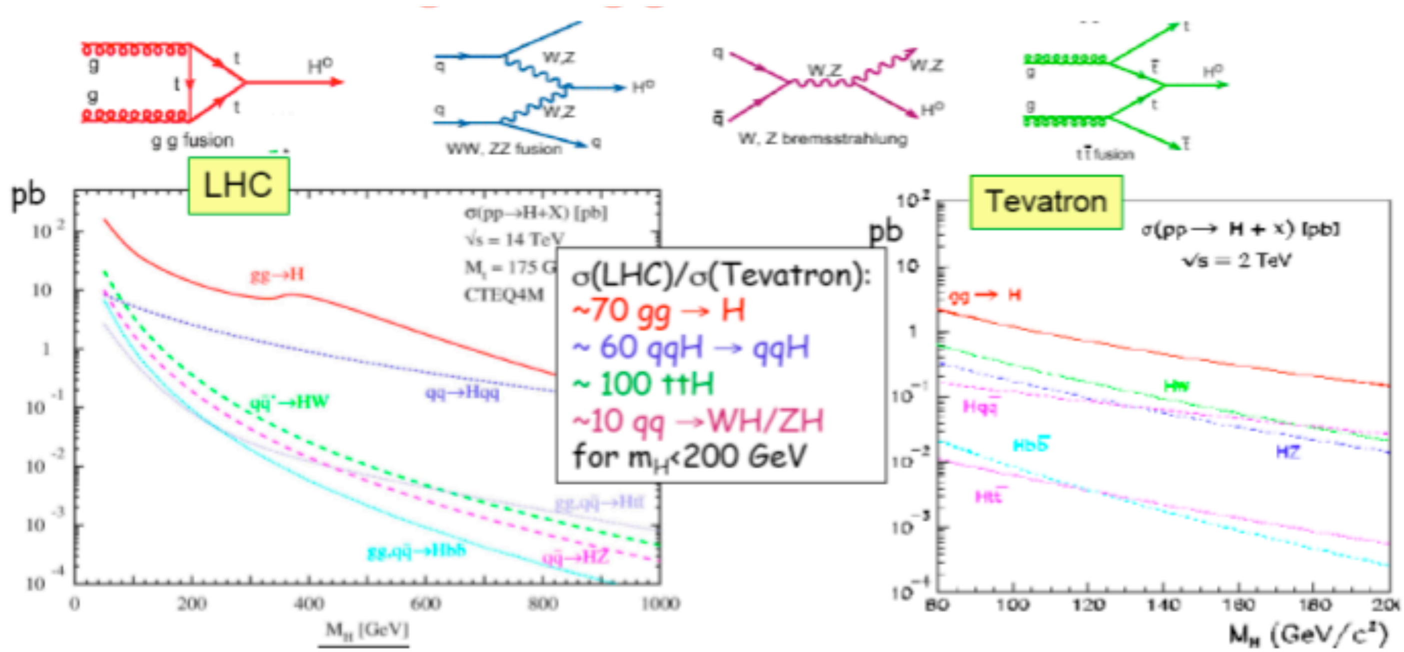


SUSY



LHC: Higgs?

Light Higgs Boson

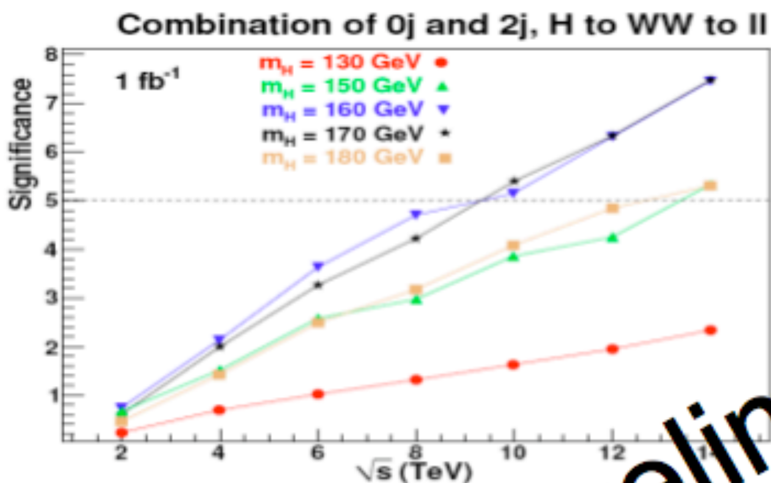


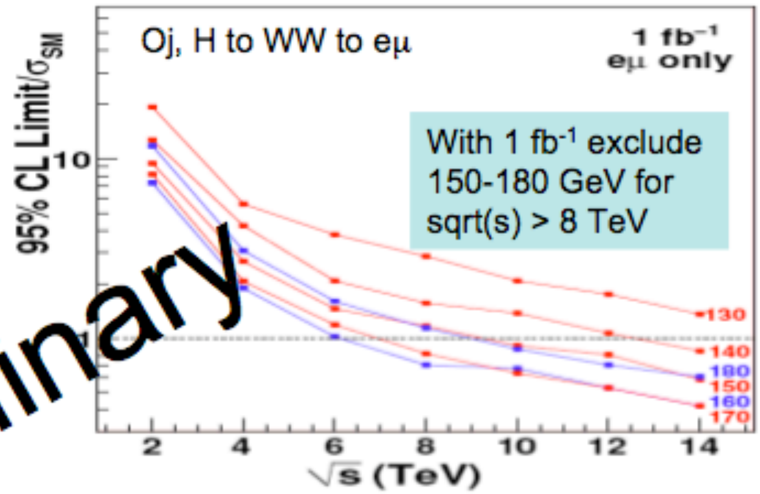
	Tevatron Main Search Channels	LHC Main Search Channels
m_H ~115 GeV	WH→ lνbb ZH → ννbb, llbb	H → γγ, qqH → qqττ ttH→ lνbbX
m_H ~ 160 GeV	H →WW → lνlν	H → WW→ lνlν,H→ZZ*→4l, qqH→ qqWW→ qqlνlν

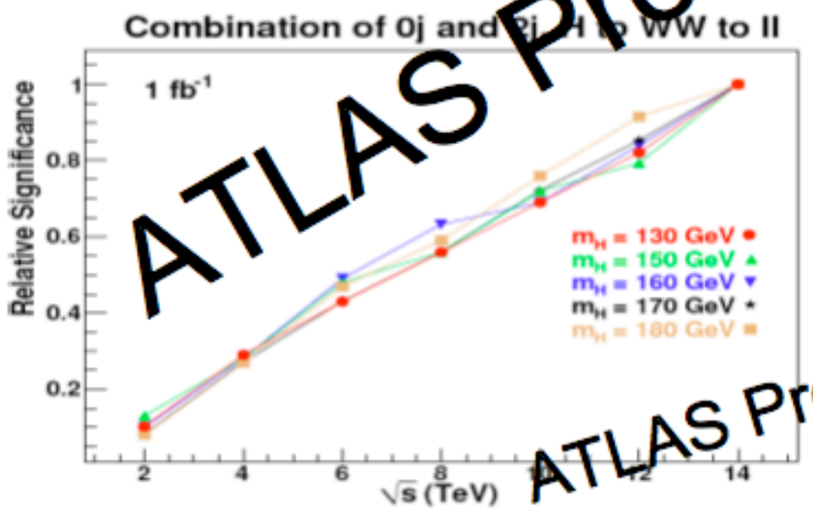
Large backgrounds at the LHC

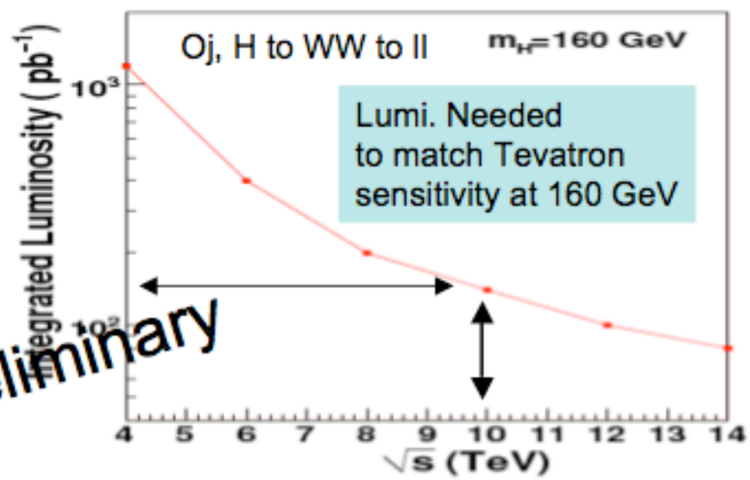
Cross-sections too small at the Tevatron

LHC: Higgs below 14 TeV









Conclusions

Hadron Collider Physics is now more exciting than ever!

From the pioneer days of the SppS we have moved to the TeVatron , where we can make precision measurements for various processes.

Many of the results interplay nicely :
from testing the SM to searches for Exotica
… same signature, different physics

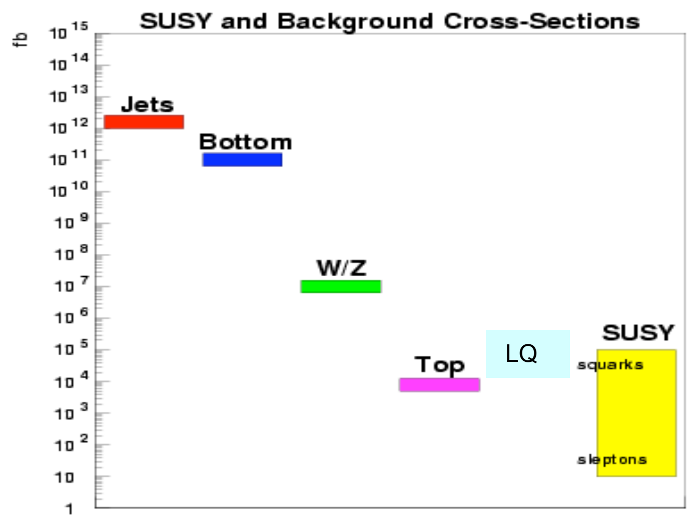
The LHC is about to start with great expectations…..

Stay Tuned!


ATLAS explores...
where quarks and gluons collide...
where forces unify...
where extra dimensions may lurk...
where dark matter reigns...
to find the truly fundamental.
the ATLAS Experiment
CERN Geneva, Switzerland
ATLAS is a particle physics experiment conducted by 34 nations at the CERN Laboratory in Geneva, Switzerland. It will explore the fundamental nature of matter and the basic forces that shape our Universe. This poster is available from CERN. The ATLAS statue image is courtesy of NYCTourist.com

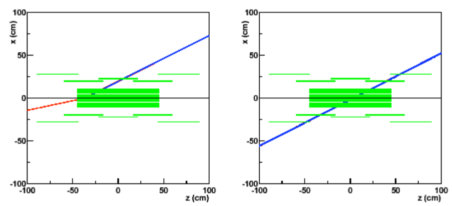
Backup Slides

Physics Processes Relative Cross Sections



Efficiency and Acceptance

- Detectors are not perfect
  - hermetic
  - Components failure
  - Over time degradation
- Geometric acceptance
  - Less than 4π coverage
  - Certain components only extend up to to certain angles
    - Silicon tracking

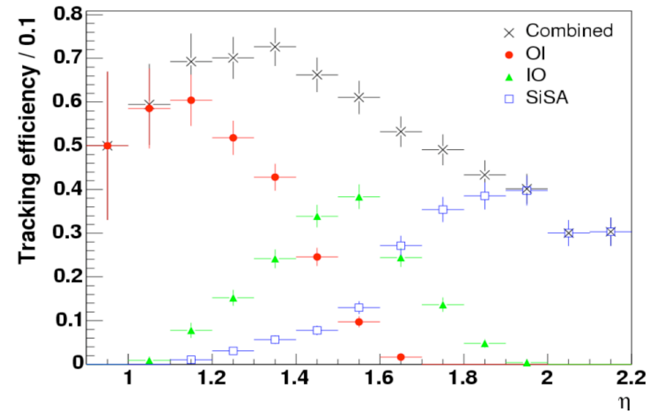


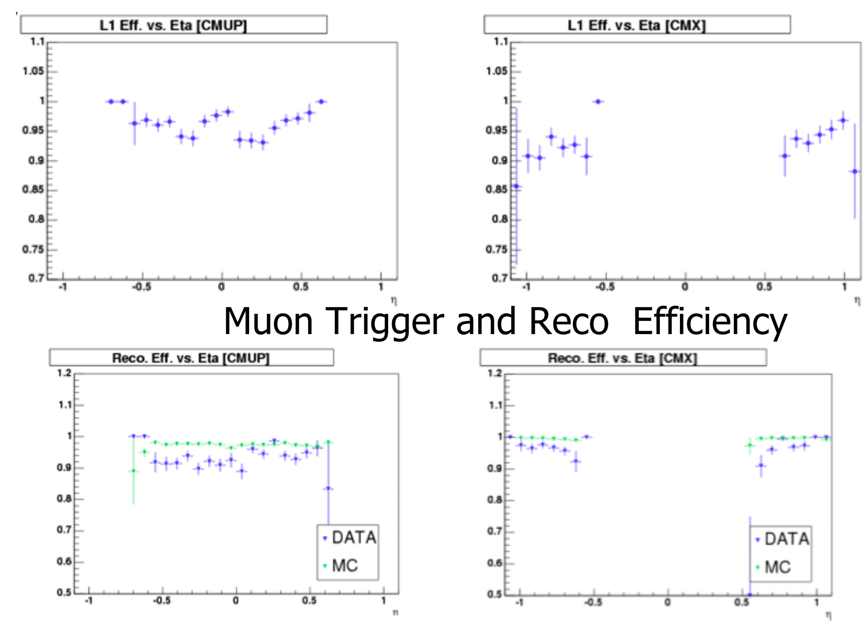
$$\eta = -\ln[\tan(\tfrac{1}{2}\theta)]$$

- Detection Efficiency
  - Trigger
  - Reconstruction
  - Identification

$$\boxed{\mathcal{R} = \sigma \times \mathcal{L} \times \varepsilon}$$

Tracking Efficiency





Muon Trigger and Reco Efficiency

TeVatron Top Mass, March 2007